Comparative Performance of Acoustic-Tagged and Passive Integrated Transponder-Tagged Juvenile Salmonids in the Columbia and Snake Rivers, 2007

A. Michelle Wargo Rub,[†] Richard S. Brown,[‡] Benjamin P. Sandford,[†] Katherine A. Deters,[‡] Lyle G. Gilbreath,[†] Mark S. Myers,[†] Mark E. Peterson,[†] Ryan A. Harnish,[‡] Eric W. Oldenburg,[‡] Jessica A. Carter,[‡] Ian W. Welch,[‡] Geoffrey A. McMichael,[‡] James W. Boyd,[‡] Eric E. Hockersmith,[†] and Gene M. Matthews[†]

Report of research by

[†]Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Blvd. East
Seattle, Washington 98112

and

[‡]Ecology Group, Pacific Northwest National Laboratory
P.O. Box 999, MS K6-85
Richland, Washington 99352

for

Environmental Resources Branch, Planning and Engineering Division
Portland District, U.S. Army Corps of Engineers
Robert Duncan Plaza
333 S.W. 1st Avenue
Portland, Oregon 97208-2946
Contract W66QKZ60441152

March 2009

PREFACE

Telemetry technology has been used extensively to investigate patterns of fish migration, survival, and behavior (Winter 1996; Bridger and Booth 2003). Both radio and acoustic telemetry are appealing to fisheries researchers because the high detection rates of these tags allow studies with smaller sample sizes (Skalski et al. 1998). Furthermore, detection systems for radio and acoustic transmitters include both stationary and mobile receivers. Stationary receivers have been deployed in freshwater, estuarine, and ocean (continental shelf and slope) environments, and mobile tracking has been used on water (acoustic and radio studies) and remotely from the shore (radio studies). This broad and flexible spatial coverage can provide more detail on behavior and movement of individuals throughout the life of a given transmitter than other forms of telemetry such as the passive integrated transponder (PIT) tag (Winter 1996). As the number of fish stocks listed under the Endangered Species Act (ESA) grows, comprehensive and efficient research tools such as acoustic and radio telemetry become more attractive for studying survival and behavior in aquatic species.

In recent years, radio and acoustic transmitters have been miniaturized significantly, prompting their use in smaller fish such as juvenile salmonids. Within the past 15 years, both radio and acoustic telemetry have been used extensively in the Snake and Columbia Rivers to evaluate surface bypass collectors (Adams et al. 1996, 1997; Hensleigh et al. 1997), turbine survival (Absolon et al. 2003), and dam passage behavior and survival (Eppard et al. 1998, 2002, 2005a,b; Anglea et al. 2001; Ploskey et al. 2001; Axel et al. 2003, 2004a,b; Hockersmith et al. 2005). However, most of these studies have been conducted on relatively small spatial scales, estimating survival past a single dam or through a particular river reach.

Restricting the use of these technologies over space and time has largely been based on results from a pair of studies conducted in the late 1990s. In 1997, Hockersmith et al. (1999) evaluated the performance of surgically radio-tagged yearling Chinook salmon *Oncorhynchus tshawytscha* migrating over distance of 238 km to Lower Granite Dam on the Snake River. Radio-tagged fish were compared to PIT-tagged cohorts released simultaneously from Lookingglass Hatchery on the Grande Ronde River. Results from this study indicated that the presence of a radio tag significantly affected growth, travel time, and survival compared to PIT-tagged fish. Radio-tagged fish passed Lower Granite Dam sooner, at a smaller size, and with reduced survival compared to PIT-tagged fish. These researchers suggested that the observed negative effects of the radio tag on fish performance may have been exaggerated by the great distance over which performance was measured.

A follow-up study in 1999 (Hockersmith et al. 2003) confirmed that regardless of tagging method (e.g. surgical or gastric), radio-tagged fish had lower survival than PIT-tagged fish over a migration distance of 225 km and travel time greater than 10 d. However, survival and migration rates for radio-tagged fish were similar to those of PIT-tagged fish over 6 d or less and within a migration distance of 106 km. The tag-weight to body-weight ratio experienced by fish in this study ranged from 1.3 to 7.0%.

The project-specific nature of past telemetry studies within the Columbia River Basin have made it difficult to extrapolate results from a single study to the river or run at large. Furthermore, differing technologies (acoustic or radio) and methodologies among sites often preclude merging results from two or more locations. To address these issues, the U.S. Army Corps of Engineers envisions development of a single tagging system to provide information on the migration and survival of juvenile fish in a consistent and continuous manner through the hydropower system and into the estuary and ocean. Additional goals of such a system are to promote data sharing among studies, reduce impacts on the resource, and improve efficiency in the use of public funds.

As a comprehensive tool for studying the life history of anadromous salmonids in the Columbia River Basin, acoustic telemetry has several advantages over radio telemetry. For example, radio signals attenuate quickly in saltwater and deep water, whereas acoustic signals are much less affected by these conditions (Winter 1996). Radio transmitters also require a trailing antenna, which may affect swimming performance, predator avoidance, and ultimately survival of tagged individuals (Adams et al. 1998a; Brown et al. 1999; Murchie et al. 2004). However, past studies have demonstrated that acoustic telemetry may not yet be sufficiently benign for use in the juvenile salmonid population at large.

In 2006, a pilot study was conducted to compare survival and behavior of yearling Chinook salmon tagged with the recently developed Juvenile Salmonid Acoustic Telemetry System (JSATS) acoustic transmitters (McComas et al. 2005) to those tagged with PIT tags as fish migrated through the (FCRPS) (Hockersmith et al., 2007). At the time, JSATS acoustic transmitters were approximately 40% smaller than the radio transmitters used by Hockersmith et al. (2003) and acoustic transmitters used by Skalski et al. (2003 and 2005).

The pilot study found that travel times for acoustic- and PIT-tagged fish were not significantly different from release to detection for the majority of downstream detection sites evaluated (Hockersmith et al. 2007). Differences in PIT-tag detection probabilities between acoustic- and PIT-tagged fish at each downstream site were less than 2%. Similarly, Hockersmith et al. (2007) found no significant difference in estimated survival between tag types from release to each detection site, with the exception of the first reach (Lower Granite to Little Goose Dam tailrace) where acoustic-tagged fish had higher survival than PIT-tagged fish. However, lack of replication and low sample sizes undermined the weight of this study, and the authors recommended the work be repeated before definitive conclusions were drawn regarding the effects of JSATS tags.

Concurrent laboratory studies were conducted in 2006 to evaluate the potential effects of the JSATS tag on growth, mortality, tag loss, and predator avoidance in yearling and subyearling Chinook salmon (Brown et al. 2007a,b; Liedtke et al. 2007). Similar to the field study, laboratory results indicated no significant differences in survival among acoustic- and PIT-tagged hatchery-reared yearling and subyearling Chinook salmon through the 90 d study period (Brown et al. 2007a). No significant differences were found in growth between acoustic- and PIT- tagged fish 21 or 90 d after tag implantation. The minimum fish length at which surgical implantation of a JSATS transmitter and a PIT tag did not negatively influence growth of juvenile Chinook salmon was 88 mm FL (Brown et al. 2007b). The minimum fish length at which surgical implantation of a JSATS transmitter and a PIT tag did not negatively influence survival was 95 mm FL (7.6% tag burden by weight). Predator avoidance was not significantly different between acoustic- and PIT-tagged subyearling Chinook, and there was no evidence of differential predation between study groups (Liedtke et al. 2007).

Encouraged by the preliminary results, as well as by an additional 8% reduction in tag size, we continued both the field and laboratory work completed in 2006 by Hockersmith et al. (2007), Brown et al. (2007a,b), and Liedtke (et al. 2007). In 2007, we attempted to gain more definitive insight into the use of acoustic telemetry for tracking juvenile salmonids. In spring and summer 2007, we compared the relative performance of yearling and subyearling Chinook salmon implanted with both a JSATS transmitter and a PIT tag to fish implanted with only a PIT tag.

In 2007, JSATS acoustic tags were 15.8-17 mm long by 5.6-5.9 mm wide and 4.2-4.8 mm high depending on the vendor and tag model. The tags ranged in weight from 0.61-0.64 g in air (0.36-0.37 g in water), and tag volume ranged from 0.22 to 0.28 mL, During the field portion of the study, survival and behavior of the acoustic-tagged Chinook salmon was compared to that of their counterparts tagged only with PIT tags as they migrated through the FCRPS. In addition, migrating fish from each treatment group were targeted for recapture at strategic locations along the migration route. These fish were removed from the FCRPS, euthanized, and examined for tag loss, disease, and histological changes due to tag implantation. Necropsy data collected at the time of tagging was used to establish reference fish condition.

A concurrent laboratory study was conducted utilizing a representative portion of each release group to observe tag loss, tissue response to tagging, long-term survival, and levels of *Renibacterium salmoninarum* (Rs), the agent responsible for bacteria kidney disease (BKD). Coded-wire tags were collected from fish throughout the season in an attempt to connect variations in percent survival with individual hatchery release groups. Results of this study will aid in determining the suitability of acoustic telemetry to estimate short- and longer-term (up to 90 d) juvenile salmonid survival through Columbia and Snake River reservoirs and dams and through the Columbia River below Bonneville Dam (Figure 1). In addition, results will contribute to future research and development of acoustic technology, particularly with respect to the shape and size of tags, and analysis of acoustic telemetry data.

CONTENTS

EVALUATION OF ACOUSTIC TAGS IN MIGRATING JUVENILE ANADROMOUS SALMONIDS

Executive Summary

Yearling Chinook Salmon. During spring 2007, we tagged 3,818 hatchery-reared yearling spring Chinook with both acoustic and PIT tags (AT fish) and 46,714 with a PIT tag only (PIT fish). Fish were released to the tailrace of Lower Granite Dam on 10 days from 24 April through 14 May. Two slightly different acoustic tags were utilized: the JSATS 2006 (weight in air 0.64 g) and 2007 model (weight in air 0.60 g).

Average tag burden experienced by AT fish was 3.5% of body weight. Travel times, detection probabilities, and survival for AT fish were estimated from individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams. We also utilized acoustic detections from multiple acoustic arrays to calculate detection probabilities for AT fish. Migration rates, detection and survival probabilities, and avian predation rates were then compared between AT and PIT fish.

Average detection probabilities were estimated for each detection site. Mean detection probability at Little Goose Dam was significantly greater for AT than PIT fish ($P = 0.004$). However, PIT fish were significantly more likely to be detected at McNary and Bonneville Dams ($P = 0.018$ and 0.010, respectively). There were no significant differences in detection probabilities between tag groups at Lower Monumental, Ice Harbor, and John Day Dams ($P = 0.59$, 0.134, and 0.721, respectively).

Relative survival estimates (i.e., survival of AT fish/survival of PIT fish) did not differ significantly from 1.0 from release to Little Goose ($P = 0.893$), Lower Monumental ($P = 0.080$), and Ice Harbor Dams ($P = 0.285$). Relative survival to McNary Dam was 92% ($P = 0.054$) and approached significance. Relative survival was significantly different to John Day ($P = 0.010$) and Bonneville Dams ($P = 0.001$). In general, travel time from Lower Granite Dam to downstream detection sites tended to be longer for AT than PIT fish. However, the only significant difference in travel times between the two groups was at John Day Dam ($P = 0.041$).

Differences in the average recovery of PIT tags from bird colonies by treatment group were not significant ($P = 0.500$ and 0.243 for upriver and estuarine bird colonies, respectively). Overall average PIT- recovery from upriver sites was 0.8% for AT fish and 1.0% for PIT fish. Overall average PIT-tag recovery from estuarine sites was 3.3% for AT fish and 2.7% for PIT fish.

Subyearling Chinook Salmon. During summer 2007, we tagged 9,833 river-run subyearling Chinook salmon with both acoustic and PIT tags and an additional 25,644 of these fish with PIT tags only (PIT fish). For subyearling Chinook salmon, we conducted separate evaluations for AT (≥95 mm) and AT pilot (85-94 mm) fish. Average tag burden for fish with both a PIT and acoustic tag was 5.6% (range 1.7-11.3) for AT fish and 9.6% (range 6.8-15.1%) for the AT pilot fish. Subyearling Chinook were released to the tailrace of Lower Granite Dam on 27 days from 4 June to 13 July. Model 2007 JSATS acoustic transmitters (weight in air 0.61g) were used exclusively during this part of the study. Survival and travel time was not evaluated for the AT pilot fish, as too few of them were detected at downstream sites for meaningful analysis.

Mean probabilities of detection and survival for AT fish were estimated from Lower Granite to Little Goose and McNary Dam. Detection and survival probabilities, along with migration and avian predation rates, were then compared between AT and PIT fish. Due to low numbers of detections for this treatment group at Lower Monumental, Ice Harbor, John Day, and Bonneville Dam, we were unable to calculate reliable estimates of detection or survival at these sites.

Mean detection probability was greater for AT fish than PIT fish at Little Goose Dam ($P = 0.001$). There was no significant difference in mean detection probability between groups at McNary Dam ($P = 0.505$). Average survival from Lower Granite to Little Goose Dam was significantly higher for PIT than AT fish ($P = 0.003$), as was survival to McNary Dam ($P = 0.001$). Fish belonging to the AT group took significantly more time ($P < 0.05$) than PIT fish to travel from Lower Granite to Little Goose, Lower Monumental, Ice Harbor, and McNary Dams.

For fish released before 30 June 2007, overall average PIT-tag recovery from upriver bird colonies was 1.3% for AT fish and 1.7% for PIT fish. The difference between the two groups was not statistically significant ($P = 0.254$). For fish released before 30 June, PIT-tag recovery from estuarine sites was 2.5% for AT fish and 2.0% for PIT fish, and the difference was not statistically significant ($P = 0.389$). Due to a combination of low survival to the estuary and low PIT tag recoveries on colonies from fish released on or after 30 June, we were unable to make reliable comparisons of predation for these fish.

Introduction

During spring and summer 2007, we compared survival and behavior of yearling and subyearling Chinook salmon implanted with both a JSATS transmitter and a PIT tag to fish implanted with a PIT tag only as they migrated through the FCRPS. Study fish were collected, tagged and released at Lower Granite Dam and recovered (detected) at downstream dams (Figure 1). In addition, we compared the percentage of tags recovered from piscivorous waterbird nesting sites by treatment to determine if one group was more vulnerable to avian predation than the other.

The study area included a 695-km reach of river from Lower Granite Dam on the lower Snake River to the mouth of the Columbia River (Figure 1). Lower Granite Dam is the fourth dam upstream from the mouth of the Snake River and is located in Washington State 173 km above the confluence of the Snake and Columbia Rivers.

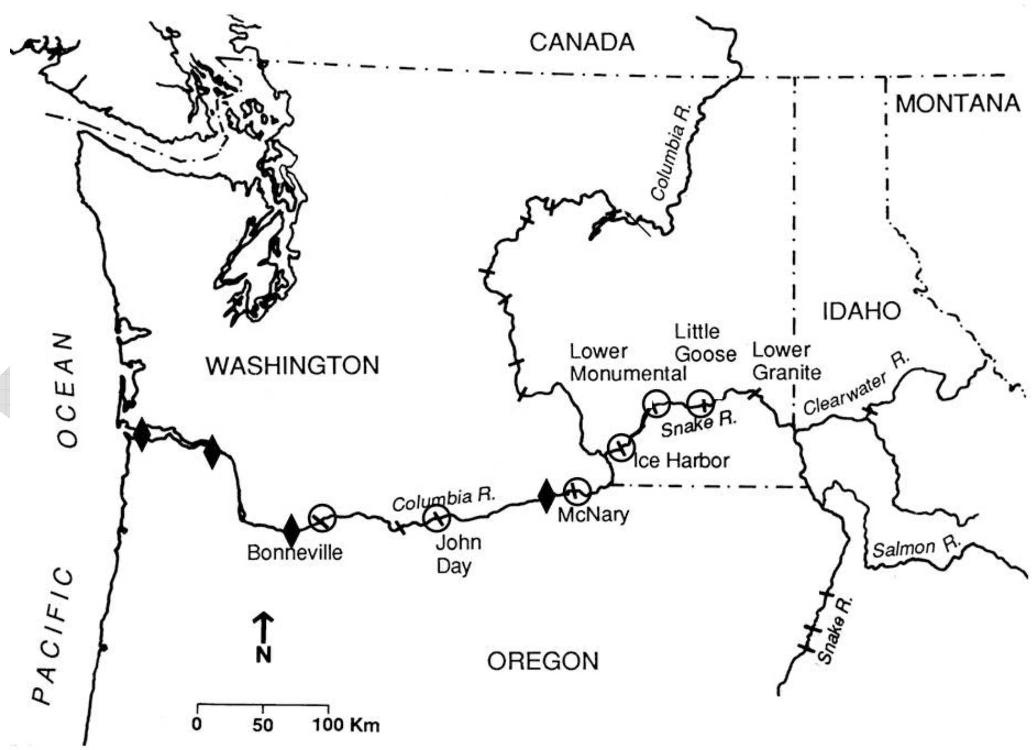


Figure 1. Detail of the field study area showing release location at Lower Granite Dam and PIT-tag detection facilities. Circles show locations of PIT-tag monitors used to evaluate travel times, detection probabilities, and survival. Black diamonds indicate locations of acoustic arrays used to estimate detection probabilities.

River discharge in the Snake River was below the 10-year average during most of the 2007 study period for both yearling and subyearling Chinook salmon (24 April-9 July and 5 June-7 September, respectively) (Figure 2). Discharge at McNary Dam was above the 10-year average during most of the yearling study and below the 10-year average during much of the subyearling study (Figure 2).

Water temperatures in the Snake and Columbia Rivers during both the yearling and subyearling study periods were similar to the 10-year average (Figure 2). Water temperature varied throughout the two study periods at Lower Granite Dam and increased linearly at McNary Dam from April through July. In early August, water temperature at McNary Dam peaked at approximately 21°C and remained above 18°C through the end of September.

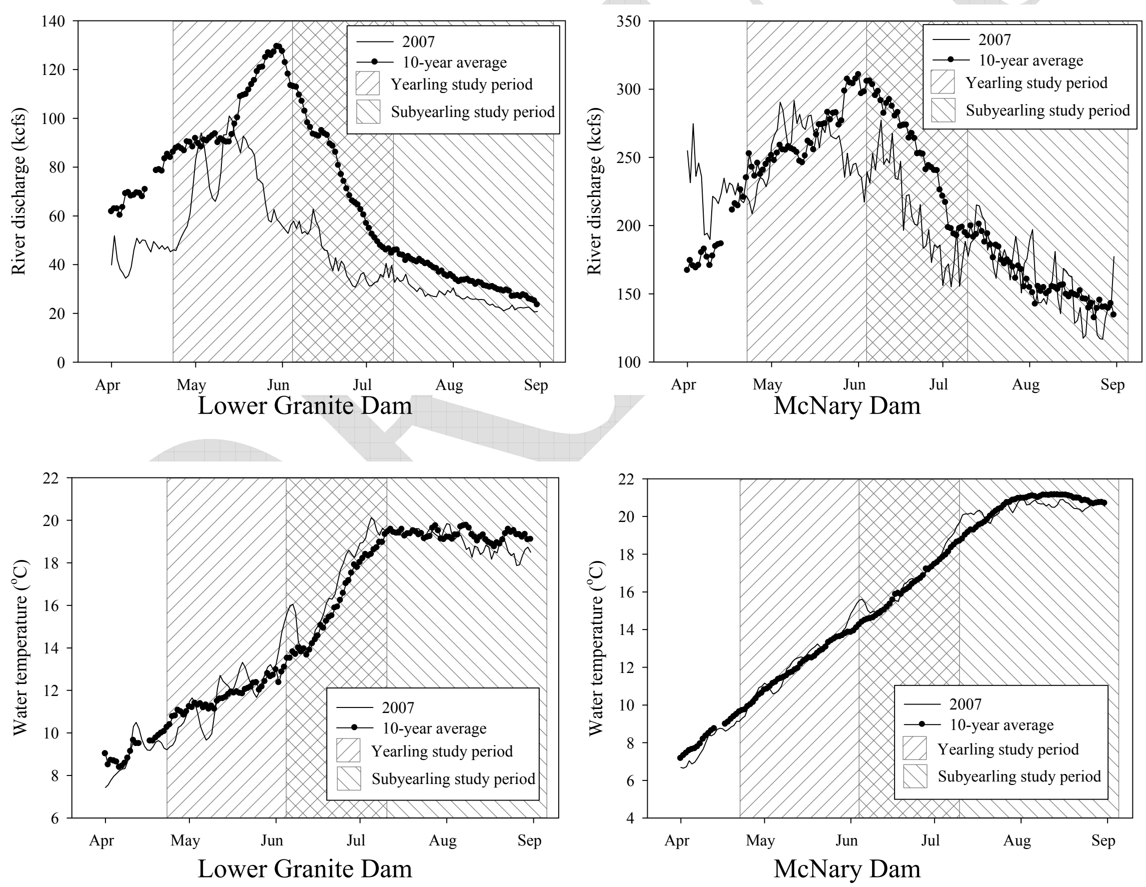


Figure 2. Upper charts show discharge at Lower Granite and McNary Dam during the study period in 2007 compared to the 10-year average (1997-2006). Lower charts show water temperature at Lower Granite and McNary Dams compared to the 10-year average (1997-2006).

Methods

Fish Collection, Tagging, and Release

Yearling Chinook Salmon—River-run, hatchery-origin yearling Chinook salmon smolts were collected from the smolt collection facility at Lower Granite Dam between 21 April and 13 May. Fish from the run at large were collected from the river between 1900 and 0700 PDT and diverted to a concrete raceway for holding. Within 12-18 h of collection, fish were sorted under light anesthesia using clove oil as an induction agent followed by tricaine methanesulfonate (MS-222; Marsh et al. 1996, 2001).

We tagged only hatchery yearling Chinook that had not been previously PIT tagged, had no visual signs of disease or injury, and measured at least 95 mm FL. Fish selected for PIT-tagging only (PIT fish) were tagged immediately following sorting. Collection and handling techniques followed the methods described in Marsh et al. (1996, 2001). Fish were measured and injected with PIT tags using a method similar to Prentice et al. (1990a,b). To reduce the likelihood of disease transmission between test fish, all needles and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 minutes prior to use.

Fish selected for acoustic tagging (AT fish) were collected in 20-L plastic buckets directly after sorting and transferred to a 75-L holding tank where they were allowed to recover from the anesthetic. Fish were then held overnight in flow-through river water prior to tagging. As such, AT fish were subjected to 18-24 h of additional holding compared to PIT-only fish.

Prior to surgery, AT fish were placed in an anesthetic bath containing MS-222 in concentrations ranging from 50 to 80 mg/L until they reached stage 4 anesthesia (loss of equilibrium; Summerfelt and Smith 1990). Temperature and pH of the anesthetic bath was monitored several times daily to ensure that temperature did not increase more than 2°C during a tagging session and that pH did not drop below 7.0. Frequent water/anesthetic changes and the addition of sodium bicarbonate as a buffering agent were used to maintain these conditions. After reaching stage 4 anesthesia, fish were removed from the anesthetic bath and transferred in 1-L plastic cups to a data station where they were weighed and measured.

After pre-processing, fish were placed on a surgery table ventral side up and administered additional anesthesia over their gills through rubber tubing via gravity feed in quantities of 50 mg/L MS-222, pure river water, or a combination of both anesthetic and pure river water. The decision to administer additional anesthetic to the fish or to perform surgery while administering pure river water was left to the individual surgeon and based on achieving a balance between maintaining a level plane of stage 4 anesthesia throughout the surgical process and allowing for rapid post-operative recovery.

Surgical tagging was conducted simultaneously at up to four tagging stations with approximately 75-100 acoustic tags implanted per hour. All surgical tools were sterilized in a steam autoclave prior to the start of each tagging day. All acoustic transmitters and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 minutes and rinsed in distilled water prior to use. Suture material and surgical tools were disinfected and rinsed in the same manner between consecutive surgeries.

Once the desired level of anesthesia was reached, a 6-8 mm incision was made 2-5 mm from and parallel to the mid-ventral line (linea alba) just anterior of the pelvic girdle of each fish. Incisions were made using either a 3.0-mm Micro-Unitome blade[1] (BD Medical Supplies), a number 10 scalpel blade, or a combination of both. First a PIT tag and then an acoustic tag was inserted into the peritoneal cavity through the surgical opening. Following tag insertion, each incision was closed with two 5-0 absorbable monofilament sutures placed in a simple interrupted pattern.

Immediately following tagging, AT fish were placed into 75-L oxygenated recovery containers and held for a minimum of 2 h for anesthetic recovery and to observe for post-tagging mortality. Implanted fish were then transferred water-to-water to an 18,500-L holding tank supplied with flow-through river water and commingled with the PIT fish that were tagged on the same day.

Following a post-tagging recovery period of 12-24 h, AT and PIT fish tagged on the same day were released simultaneously into the tailrace of Lower Granite Dam. Fish were released by connecting their common holding tank to the juvenile bypass system outfall pipe with a 10.2-cm diameter flexible hose (PSMFC 2004). All fish tagged and released for this study were assigned a "no transport" designation in the PTAGIS system. This classification ensured that our study fish would not be placed on barges if they were collected at downstream dams. Yearling Chinook salmon belonging to the PIT fish group served a dual purpose as both reference fish for our comparisons to acoustic-tagged fish and as "inriver migrants" for the BPA-funded latent mortality (BPA Project 2003-041-00).

[1] Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

A total of 3,818 AT fish and 46,714 PIT fish were released over 12 d into the tailrace of Lower Granite Dam (Table 1). The first release on 25 April coincided with detection of the 20th percentile of the cumulative smolt index for yearling Chinook salmon passing Lower Granite Dam in 2007, and the final release on 15 May coincided with the 93rd percentile (Figure 3).

Table 1. Number and mean fork length of AT and PIT fish released at Lower Granite Dam in 2007.

	Yearling Chinook salmon					
	AT fish			PIT fish		
Release date	N	Fork length (mm)	SD	N	Fork length (mm)	SD
24 April	0	-	-	4512	133.8	13.2
25 April	404	130.7	11.6	0	-	-
26 April	397	131.4	11.1	3769	129.6	11.2
28 April	404	133.4	11.5	3334	129.3	11.9
1 May	403	130.9	10.4	3792	132.2	10.0
3 May	406	132.7	10.3	8040	132.0	10.7
5 May	412	135.0	8.1	5579	135.0	10.0
8 May	0	-	-	3561	133.9	9.7
9 May	414	133.4	9.7	0	-	-
10 May	299	135.6	7.8	4773	134.1	9.4
12 May	311	133.7	8.6	4804	135.1	8.3
15 May	368	133.8	8.3	4550	135.0	9.1
Total	3818	133.0	9.9	46714	133.2	10.6

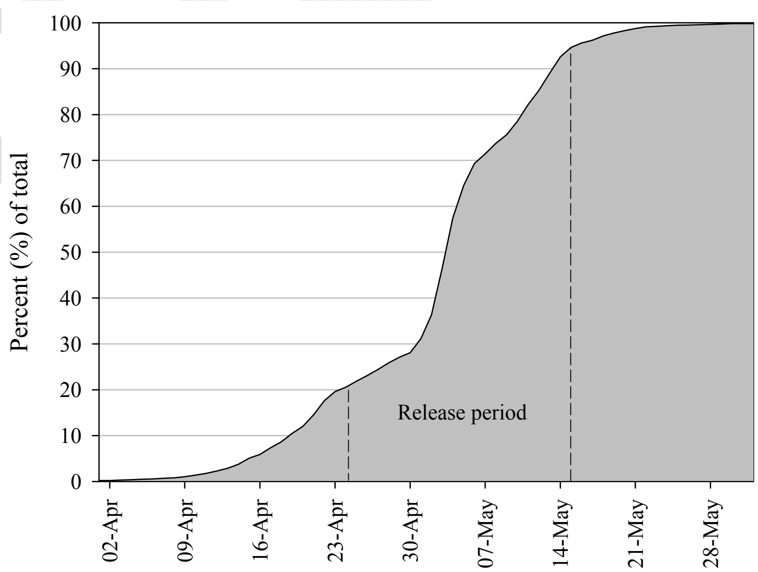


Figure 3. Cumulative passage distribution of yearling Chinook salmon at Lower Granite Dam in 2007.

AT fish had a mean fork length of 133 mm, mean weight of 22.4 g, and experienced a mean tag burden of 3.5% from the combined presence of the acoustic transmitter and PIT tag. Average tag burden from the acoustic tag alone was 2.9%. PIT-tagged fish had a mean fork length of 133 mm, and weights were not obtained for the PIT fish. Fork lengths of AT and PIT fish were representative of the general population of river-run yearling Chinook salmon sampled by the smolt monitoring program (SMP) during the study period. Average fork lengths among study fish and SMP sample fish were similar on most release days (Figures 4 and 5).

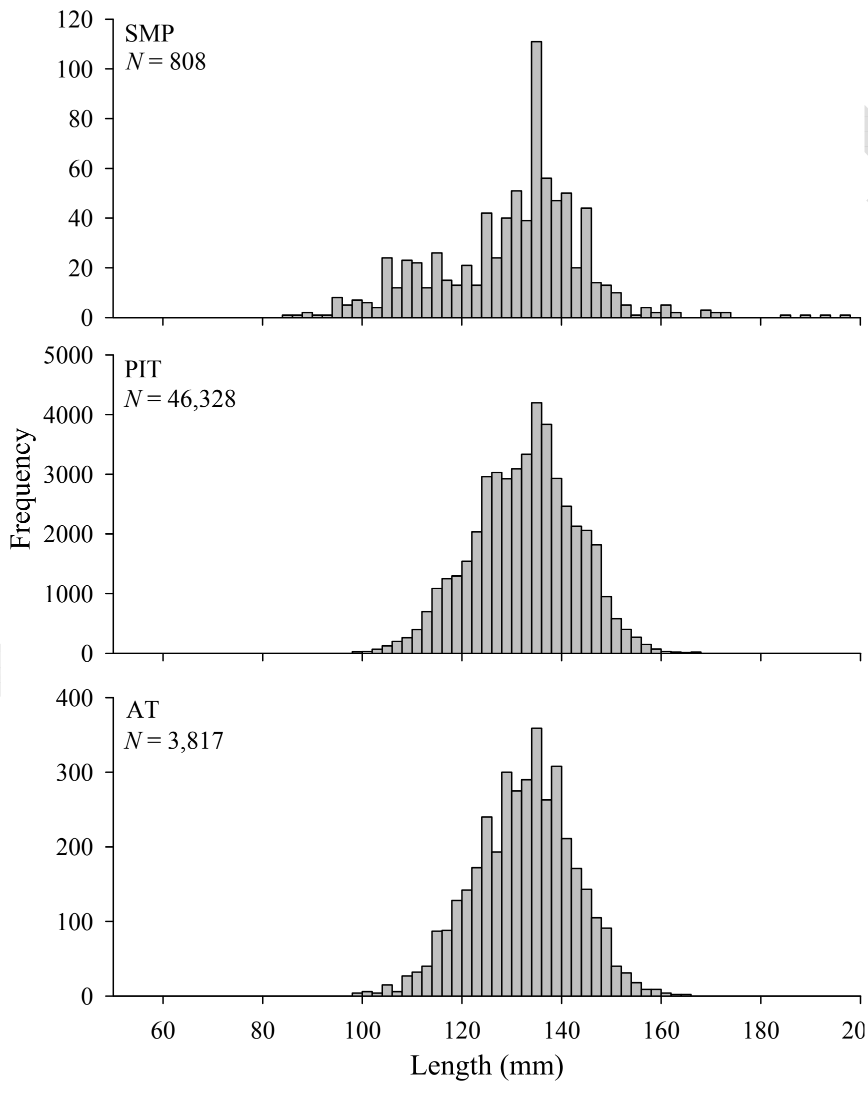


Figure 4. Length frequency histograms (2-mm bins) comparing fork lengths of yearling Chinook salmon sampled by the smolt monitoring program (SMP) to AT and PIT yearling Chinook salmon released at Lower Granite Dam in 2007. Smolt monitoring program data provided by the Fish Passage Center.

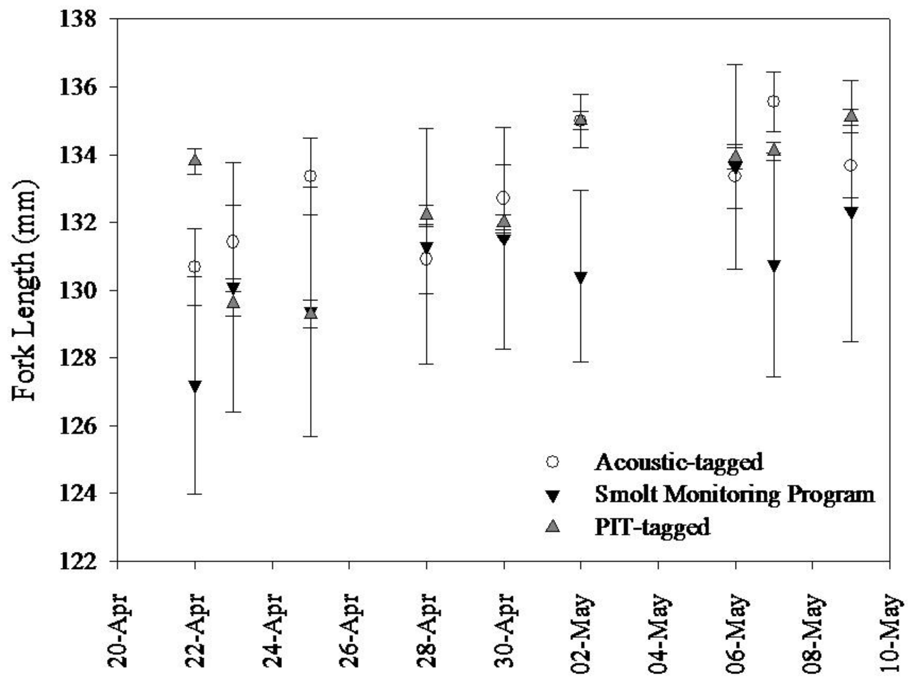


Figure 5. Mean fork lengths (whiskers represent 95% confidence intervals) of AT and PIT yearling Chinook salmon and yearling Chinook salmon sampled by the SMP at Lower Granite Dam in 2007. SMP data provided by the Fish Passage Center.

Individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams were utilized to estimate travel time and detection and survival probabilities for PIT fish. PIT-tag detections at these sites, along with acoustic detections from Irrigon, Bonneville, and the lower river and estuary, were utilized to estimate detection probabilities for AT fish. Travel times for AT fish were based solely on PIT-tag detections. These estimates, along with avian predation rates, were compared between AT and PIT fish groups.

Fish were implanted with either 2006 or 2007 JSATS acoustic transmitters manufactured by Sonic Concepts. Each acoustic tag transmitted a uniquely coded 31-bit binary phase-shift keyed signal at a frequency of 416.7 kHz and at a minimum source level of 150 dB (relative to 1 μPascal at 1 minute). The pulse rate interval was 10 seconds, and minimum tag life was 55 d. Tags were activated 1-2 d prior to tagging by a small solder connection, which was then sealed by UV-activated epoxy. Dimensions of the two JSATS acoustic tag models are compared below, along with dimensions of the TX-1400ST (ST) PIT tag.

	JSATS Acoustic tags (SD)		
	2006	2007	ST PIT tag (SD)
Length (mm)	17.0 (0.2),	16.1 (0.2)	12.48 (0.1)
height (mm)	4.8 (0.2),	4.1 (0.1)	
width (mm)	5.9 (0.1),	5.9 (0.1)	
weight in air (g)	0.64 (0.001)	0.6 (0.007)	0.1020 (0.0010)
mean mass in water (g)	0.36 (0.007)	0.38 (0.005)	
mean volume (mL)	0.28	0.24	
diameter (mm)			2.07 (0.02)
mean tag burden (% body)	2.9 (range 1.3-7.7)		0.5 (range 0.2-1.2)

Subyearling Chinook Salmon—River-run hatchery and wild subyearling Chinook salmon were collected from the smolt collection facility at Lower Granite Dam from 2 June to 12 July 2007. Study fish were collected, handled, and tagged in a manner similar to that described above for yearling Chinook salmon with one exception. Acoustic-tagged subyearling fish were allocated to two AT groups based on size at tagging. The main test group (AT fish) consisted of subyearling fish that were 95 mm FL or longer. A second pilot group (AT pilot fish) consisted of fish that measured 85-94 mm FL. All PIT-tagged fish measured at least 82 mm FL.

Totals of 7,736 AT fish, 2,097 AT pilot fish, and 25,644 PIT fish were released to the tailrace of Lower Granite Dam (Table 2). The first release on 5 June coincided with detection of the 26th percentile of the cumulative smolt index for subyearling Chinook salmon passing Lower Granite Dam in 2007, and the final release on 14 July coincided with the 91st percentile (Figure 6).

AT fish had a mean fork length of 107 mm, mean mass of 12.8 g, and experienced a mean tag burden of 5.6% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the PIT tag alone was 0.9% (range 0.3-1.7%). AT pilot fish had a mean fork length of 91 mm, mean weight of 7.5 g, and experienced a mean tag burden of 9.6% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the presence of the PIT tag alone was 1.5%. PIT fish had a mean fork length of 108 mm, a mean weight of 13.8 g, and experienced a mean tag burden of 0.7%.

Table 2. Number and mean fork length of AT pilot, AT, and PIT subyearling Chinook salmon released at Lower Granite Dam in 2007.

	Subyearling Chinook Salmon								
	AT pilot (85-94 mm)			AT (≥95 mm)			PIT-tag		
Release date	N	Fork length (mm)	SD	N	Fork length (mm)	SD	N	Fork length (mm)	SD
5 June	90	88.9	2.3	260	105.3	6.7	1,096	106.0	6.5
6 June	87	89.9	2.7	267	104.1	5.9	1,171	105.1	6.5
7 June	91	89.0	2.6	263	103.7	5.6	1,131	104.6	6.4
8 June	89	88.9	2.7	263	103.7	5.0	1,081	105.7	5.5
9 June	81	89.6	2.9	271	103.8	5.2	1,133	106.9	6.0
12 June	89	91.3	2.5	261	104.6	5.4	1,070	105.6	5.6
13 June	92	90.9	2.5	270	103.6	5.7	1,143	106.4	6.4
14 June	113	90.8	2.7	308	103.4	5.9	1,075	107.0	6.9
15 June	103	90.7	2.6	323	103.0	5.7	895	107.5	6.9
16 June	127	89.9	2.5	270	101.6	5.2	1,240	107.4	6.1
19 June	104	90.8	2.5	328	108.5	7.6	1,225	109.0	7.8
20 June	106	90.5	2.4	247	105.1	6.4	906	109.2	7.6
21 June	97	91.2	2.6	273	105.7	6.6	1,670	109.5	7.9
22 June	89	91.0	2.3	320	106.1	6.9	0	-	-
23 June	108	90.8	2.5	302	106.7	7.4	1,002	111.0	7.2
26 June	79	90.5	2.5	337	107.8	6.9	1,412	108.9	7.0
27 June	98	90.6	2.8	246	106.5	6.2	1,154	108.7	6.8
28 June	116	90.8	2.7	270	106.0	5.6	973	108.5	7.0
29 June	71	90.5	2.5	243	106.7	6.3	386	109.1	7.4
30 June	59	91.2	2.8	290	106.6	6.5	616	110.4	7.0
3 July	40	90.4	2.2	271	110.7	7.5	1,089	109.7	8.2
4 July	84	91.0	2.6	292	108.6	8.1	649	111.3	8.1
5 July	53	91.7	2.4	237	107.3	8.2	605	111.2	8.5
6 July	4	89.8	3.4	137	109.6	7.7	1,448	111.5	7.5
11 July	0	-	-	0	-	-	274	111.1	8.5
12 July	2	94.0	0.1	549	111.3	8.6	771	111.2	8.7
13 July	13	91.5	2.4	329	113.6	10.0	433	110.4	8.3
14 July	12	92.1	2.3	309	111.1	8.6	767	111.8	8.9
Total	2,097	90.5	2.7	7,736	106.6	7.6	26,415	108.4	7.5

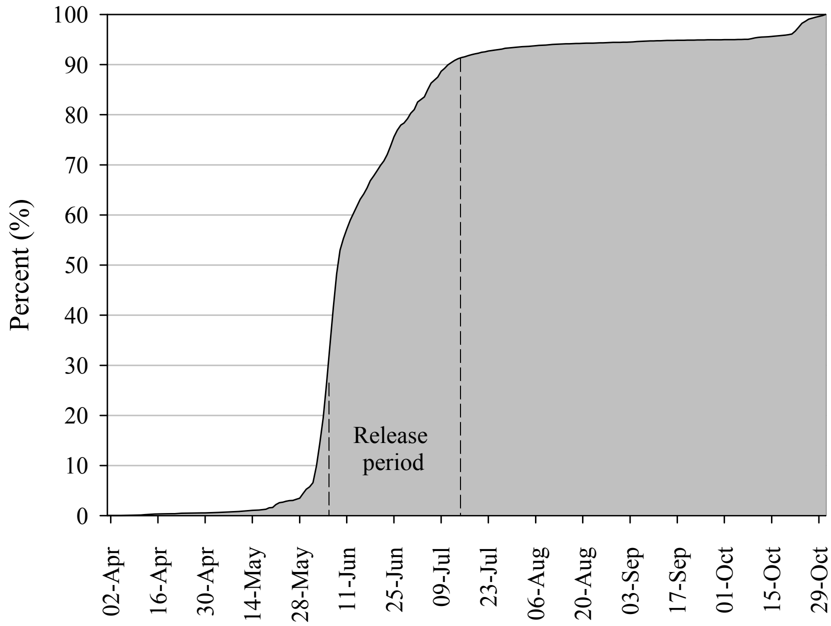


Figure 6. Cumulative passage distribution of subyearling Chinook salmon at Lower Granite Dam in 2007.

Size-frequency distributions of AT and PIT fish were similar to those of the run at large based on SMP samples (Figure 7). Mean fork length was similar among the PIT fish, the AT fish, and the SMP sample fish on most release days (Figure 8). Mean fork length of the AT Pilot fish was smaller than that of SMP sample fish on every release day (Figure 8); however, there was still a component of the SMP sample fish that measured less than the AT pilot fish.

Similar to the yearling study, individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams were utilized to estimate travel times, detection probabilities and survival for the PIT fish. PIT-tag detections at these sites, along with acoustic detections from Irrigon, Bonneville, and the lower river and estuary were utilized to estimate, detection probabilities for AT fish. Travel times for AT fish were based solely on PIT-tag detections. These estimates, along with avian predation rates, were compared between AT and PIT fish.

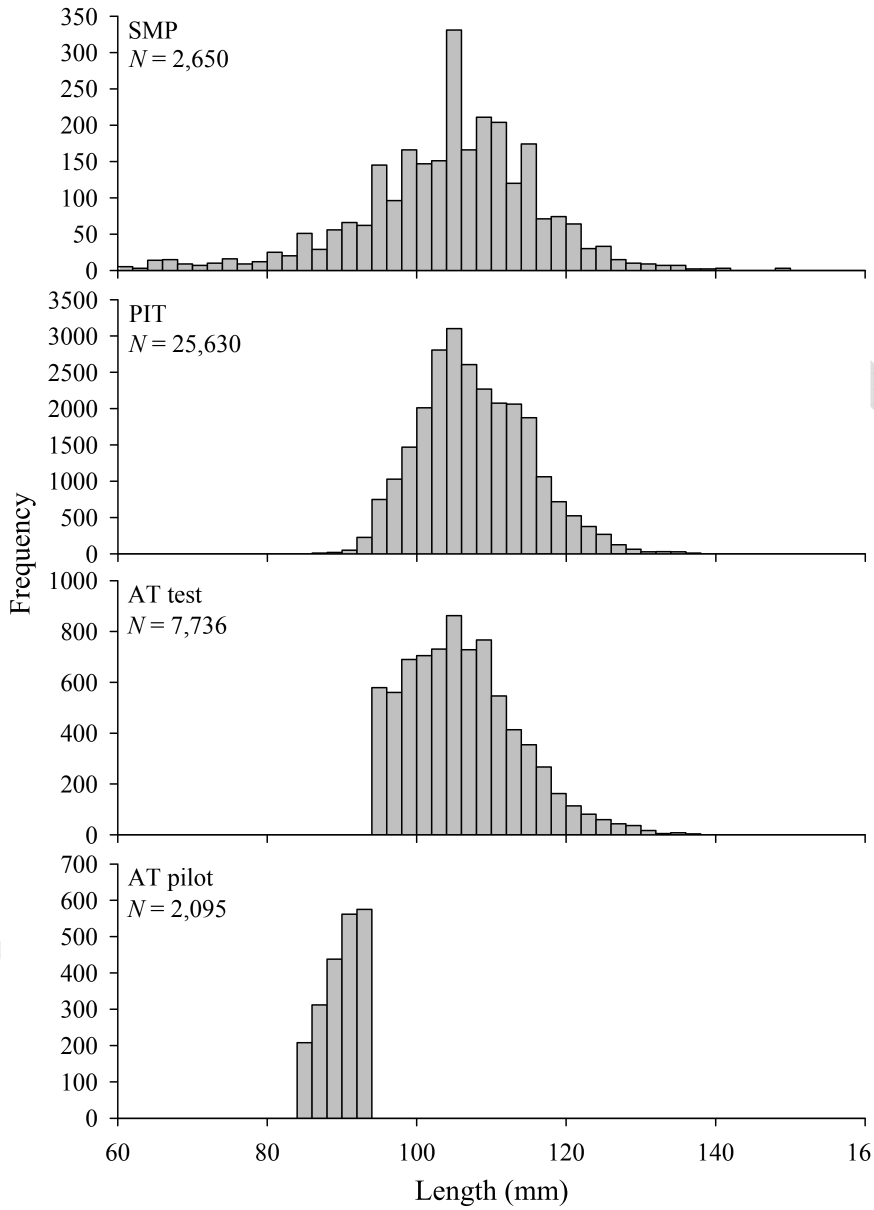


Figure 7. Length frequency histograms (2-mm bins) comparing fork lengths of subyearling Chinook salmon from the SMP sample to AT, AT pilot, and PIT fish released at Lower Granite Dam in 2007. Smolt Monitoring Program data provided by the Fish Passage Center.

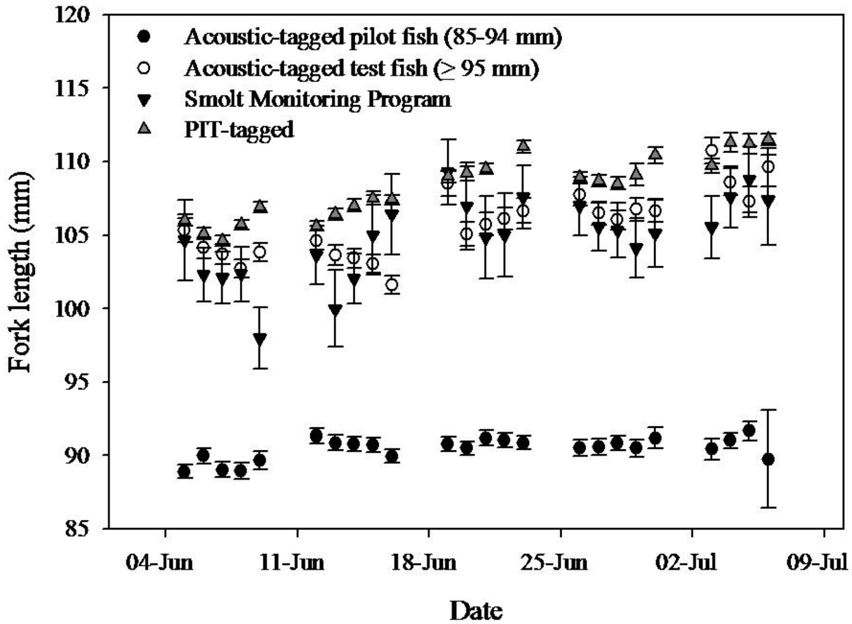


Figure 8. Mean fork lengths (whiskers represent 95% confidence intervals) of AT pilot, AT, and PIT subyearling Chinook salmon compared to those sampled by the SMP at Lower Granite Dam in 2007. SMP data were provided by the Fish Passage Center.

Subyearling Chinook salmon were implanted with JSATS acoustic transmitter tags manufactured by Advanced Telemetry Systems. Average dimension of the tags (± SD) are shown below, with dimension of PIT-tags for comparison. The pulse rate interval was 5 seconds, while other aspects of the tag signal were similar to those described above for JSATS transmitters implanted in yearling Chinook salmon. Tags were activated 1-2 d prior to tagging by placement in an electromagnetic activation dish.

Dimensions of the 2007 JSATS acoustic tag and TX-1411SST (SST) PIT tags are shown below.

	2007 JSATS tag (SD)	SST PIT tag (SD)
Length (mm)	15.8 (0.2)	12.48 (0.1)
Height (mm)	4.2 (0.2)	
Width (mm)	5.6 (0.2)	
Weight in air (g)	0.61 (0.01)	0.1020 (0.0010)
Mean mass in water (g)	0.37 (0.004)	
Mean volume (mL)	0.22	
Diameter (mm)		2.07 (0.02)
Mean tag burden (% body wt)	5.6 (range 1.7-11.3).	0.9 (range 0.2-1.2)

Detection and Survival Estimates

PIT-tag detection data for all release groups were retrieved from PTAGIS and checked for errors. Estimates of survival and detection probabilities for PIT-tagged fish were based on detection histories using the Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) and implemented using Survival with Proportional Hazards (SURPH) software (Smith et al. 1994). Detection history was a record of individual fish detections at each downstream location (and whether the tagged fish was incidentally removed from the system due to transportation or other terminal sampling). Estimates of survival probabilities under the SR model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. Standard errors for these estimates are also obtained from the model.

Detection probabilities and estimates of survival for acoustic-tagged fish were calculated using a CJS single-release model, as described above for PIT-tagged fish, with the exception that estimates of detection probability for acoustic-tagged fish were based on detection information from both PIT- and acoustic-tag detections. PIT-tag detections at Little Goose, Ice Harbor, Lower Monumental and McNary Dams were combined with acoustic detections from an acoustic array near Irrigon, Oregon to estimate detection probabilities for acoustic-tagged fish at these locations. PIT-tag detections at John Day Dam were combined with acoustic detections from an acoustic array at Bonneville Dam tailrace. Finally, PIT–tag detections at Bonneville Dam were combined with detections from multiple acoustic arrays in the lower Columbia River below Bonneville Dam and in the estuary to estimate detection probability for acoustic-tagged fish at this location. Detail on acoustic receiver nodes is provided in Appendix A.

Given the potential for acoustic-tagged fish to lose PIT tags, and the generally higher detection rates of AT fish, combining detection information for this treatment group in the manner described above, allowed us to produce a more accurate and precise estimate of survival. A full description of how the CJS model was used with the two types of detection data is presented in Appendix C.

Detection probability at each downstream dam for acoustic- and PIT-tagged fish was compared using *t*-tests on the difference of the estimated means within release groups (i.e., mean AT tag detection probability – mean PIT detection probability). For the null hypothesis, that detection probability was equal between tag groups (i.e., that the difference in detection probabilities was not different than zero), we calculated the test statistic:

$$t = \frac{\hat{P}_{Acoustic} - \hat{P}_{PIT}}{\sqrt{\hat{S}E_{P_{Acoustic}}{}^{2} - \hat{S}E_{P_{PIT}}{}^{2}}}$$

and compared it to the normal variant corresponding to α = 0.05 (i.e., 1.96). Survival estimates from release to each downstream dam were compared using *t*-tests on ratios of the means within each of the two treatment groups (AT/PIT-tag). Since ratios of proportions can be assumed to be log-normally distributed (Snedecor and Cochran 1980), we used the natural log transformation. Therefore, for the null hypothesis that survival was equal between tag groups (i.e., that the ratio was different than one or the log of the ratio was different than zero), we calculated the test statistic:

$$t = \frac{LN\left(\frac{\hat{S}_{Acoustic}}{\hat{S}_{PIT}}\right)}{\sqrt{\frac{\hat{S}E_{S_{Acoustic}}{}^{2}}{S_{Acoustic}{}^{2}} + \frac{\hat{S}E_{S_{PIT}}{}^{2}}{\hat{S}_{PIT}{}^{2}}}}$$

and compared it to the normal variant corresponding to α = 0.05 (i.e., 1.96).

$$\left[e^{LN\left(\frac{\hat{S}_{Acoustic}}{\hat{S}_{PIT}}\right) - 1.96xSE}, e^{LN\left(\frac{\hat{S}_{Acoustic}}{\hat{S}_{PIT}}\right) + 1.96xSE} \right]$$

Travel Time

Travel time was calculated for individual fish in PIT and AT groups from PIT-tag detection data that was retrieved from PTAGIS and checked for errors. Travel times were calculated from release in Lower Granite Dam tailrace to the following locations:

- Little Goose Dam (60 km),
- Lower Monumental Dam (106 km)
- Ice Harbor Dam (157 km)
- McNary Dam (225 km)
- John Day Dam (348 km)
- Bonneville Dam (460 km).

Travel time through a reach included delays both in the forebays of dams before passing and within the bypass systems.

The true set of travel times for fish in a release group includes travel time of both detected and nondetected fish. However, travel time could not be determined for fish that traversed a river section, but was not detected at one or both ends of the reach. Thus, travel-time statistics were estimated from travel time rates for detected fish only, with computations representing a sub-sample of the complete release group.

We estimated travel time for each release date separately due to temporal trend differences in travel times associated with environmental (e.g. river flow) and biological (e.g. smoltification) factors. A minimum of 10 fish from each release group had to be detected at a detection site for the group to be included in the travel time analysis. Subyearlings were grouped by week of release because relatively low numbers of acoustic-tagged subyearlings were detected from each individual release date at downstream detection sites.

Additionally, detections that occurred 55 d after the tag-activation date (the minimum life of the acoustic transmitters) were removed from the data. Median travel time to each detection site was calculated for each release group. The median was more useful as an indicator of typical travel time due to the longer right tail of individual distributions (i.e., presence of "stragglers"). The 5^{th} and 95^{th} percentile travel time values to each detection site were used to develop 95% CIs around the median travel time of each release group. Overall mean travel times between release and each downstream detection site (and 95% CIs) were calculated from the median travel times of paired replicate groups to test the null hypothesis that acoustic- and PIT-tagged groups traveled at equal rates.

Avian Predation

NOAA Fisheries and the Columbia Bird Research group annually monitor selected avian nesting colonies within the basin for PIT tags deposited by predatory waterbirds. Physical recovery and electronic detection of PIT tags on piscivorous bird colonies are conducted during fall each year, after the birds have abandoned the colonies. Data collected during fall 2007 were provided by NOAA Fisheries (D. Ledgerwood, NOAA Fisheries personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication), and included predation information from Caspian tern *Sterna caspia*, double-crested cormorant *Phalacrocorax aurtius*, and gull *Larus* spp. colonies.

Differences in the percent of tags recovered (by location and colony) were compared between AT and PIT fish using the methodology described above for PIT-tag detection probability at dams. In an attempt to adjust for unequal survival downstream between the two treatment groups, we multiplied the individual cohort release numbers by survival from Lower Granite Dam to Lower Monumental Dam (for upper river bird colonies) and to Bonneville or John Day Dams (for estuarine bird colonies in spring and summer, respectively) before calculating the proportion of fish known to be consumed. Due to a combination of low survival to the lower river, as well as very low PIT-tag recoveries from releases of subyearling Chinook on or after 30 June, avian predation was compared among treatments only for subyearling Chinook released prior to this date. There were no recoveries on bird colonies of tags from AT pilot subyearling fish, so no assessments of avian predation were made for this group.

Results

Yearling Chinook Salmon

Detection Probability—Of the 3,818 AT fish and 46,714 PIT fish released into the tailrace of Lower Granite Dam, there were 3,508 and 45,347 first-time PIT-tag detections, respectively, at downstream dams on the Snake and Columbia Rivers (Appendix D). Detection probabilities varied among release groups and detection locations (Figure 9; Tables 3 and 4). The lowest PIT-tag detection probabilities were observed at Ice Harbor and Bonneville Dams, whereas the highest detection probabilities were observed at McNary and John Day Dams (Figure 9).

Overall, mean PIT-tag detection probabilities between AT and PIT fish differed significantly (α = 0.05) at three of the six detection sites (Tables 3 and 4). At Little Goose Dam, overall mean PIT-tag detection probability of AT fish was significantly greater than that of PIT-tagged fish (P = 0.004; Table 3). Conversely, PIT-tagged fish were significantly more likely than AT fish to be detected at McNary (P = 0.018) and Bonneville (P = 0.010) Dams (Table 4).

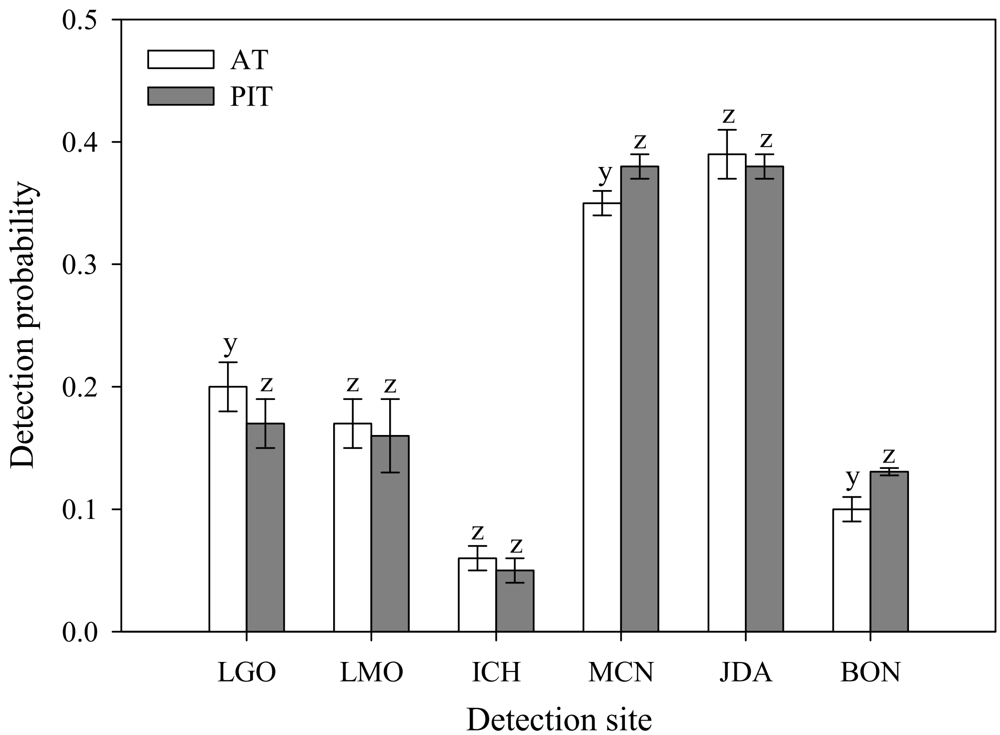


Figure 9. Mean PIT-tag detection probability of AT and PIT-tagged yearling Chinook salmon at each detection site on the Snake and Columbia Rivers in 2007. Abbreviation of dams: LGO, Little Goose; LMO, Lower Monumental; ICH, Ice Harbor; MCN, McNary; JDA, John Day; BON, Bonneville. Error bars denote standard errors. Dissimilar letters indicate a significant difference (α = 0.05) between groups at each detection site.

Table 3. Mean PIT tag detection probability and *t*-test results at each detection site in the Snake River for AT and PIT river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007 (α = 0.05). Standard errors are in parentheses.

		Mean detection probability			
Detection point	Release date	AT	PIT	*t*	*P*
Little Goose Dam	25 April	0.15 (0.02)	0.10 (0.01)		
	26 April	0.16 (0.02)	0.12 (0.01)		
	28 April	0.19 (0.02)	0.18 (0.01)		
	1 May	0.23 (0.03)	0.19 (0.01)		
	3 May	0.14 (0.02)	0.11 (< 0.01)		
	5 May	0.09 (0.02)	0.10 (0.01)		
	9 May	0.24 (0.02)	0.20 (0.01)		
	10 May	0.31 (0.03)	0.31 (0.01)		
	12 May	0.29 (0.03)	0.24 (0.01)		
	15 May	0.24 (0.03)	0.16 (0.01)		
	Mean	**0.20 (0.02)**	**0.17 (0.02)**	**3.89**	**0.004**
Lower Monumental Dam	25 April	0.17 (0.02)	0.16 (0.01)		
	26 April	0.16 (0.02)	0.17 (0.01)		
	28 April	0.14 (0.02)	0.18 (0.01)		
	1 May	0.14 (0.02)	0.11 (0.01)		
	3 May	0.05 (0.01)	0.03 (< 0.01)		
	5 May	0.17 (0.02)	0.13 (0.01)		
	9 May	0.31 (0.03)	0.32 (0.01)		
	10 May	0.24 (0.03)	0.25 (0.01)		
	12 May	0.10 (0.02)	0.09 (0.01)		
	15 May	0.19 (0.02)	0.17 (0.01)		
	Mean	**0.17 (0.02)**	**0.16 (0.03)**	**0.56**	**0.590**
Ice Harbor Dam	25 April	0.05 (0.01)	0.07 (0.01)		
	26 April	0.09 (0.02)	0.07 (0.01)		
	28 April	0.07 (0.01)	0.05 (0.01)		
	1 May	0.07 (0.02)	0.04 (< 0.01)		
	3 May	0.06 (0.02)	0.03 (< 0.01)		
	5 May	0.12 (0.02)	0.09 (0.01)		
	9 May	0.05 (0.01)	0.05 (0.01)		
	10 May	0.05 (0.02)	0.05 (< 0.01)		
	12 May	0.05 (0.01)	0.06 (< 0.01)		
	15 May	0.03 (0.01)	0.02 (< 0.01)		
	Mean	**0.06 (0.01)**	**0.05 (0.01)**	**1.65**	**0.134**

Table 4. Mean PIT-tag detection probability and *t*-test results at each detection site in the Columbia River for AT and PIT-tagged river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007 ($\alpha = 0.05$). Standard errors are in parentheses.

Detection point	Release date	Mean detection probability		*t*	*P*
		AT	PIT		
McNary Dam	25 April	0.34 (0.03)	0.42 (0.01)		
	26 April	0.37 (0.03)	0.38 (0.01)		
	28 April	0.33 (0.03)	0.37 (0.01)		
	1 May	0.38 (0.03)	0.36 (0.01)		
	3 May	0.33 (0.03)	0.33 (0.01)		
	5 May	0.30 (0.03)	0.33 (0.01)		
	9 May	0.32 (0.03)	0.33 (0.01)		
	10 May	0.37 (0.03)	0.39 (0.01)		
	12 May	0.36 (0.03)	0.42 (0.01)		
	15 May	0.40 (0.03)	0.42 (0.01)		
	Mean	**0.35 (0.01)**	**0.38 (0.01)**	**2.88**	**0.018**
John Day Dam	25 April	0.38 (0.03)	0.45 (0.02)		
	26 April	0.46 (0.04)	0.42 (0.03)		
	28 April	0.47 (0.04)	0.42 (0.03)		
	1 May	0.45 (0.04)	0.37 (0.02)		
	3 May	0.39 (0.04)	0.33 (0.02)		
	5 May	0.34 (0.03)	0.33 (0.02)		
	9 May	0.41 (0.04)	0.35 (0.02)		
	10 May	0.31 (0.04)	0.41 (0.02)		
	12 May	0.33 (0.05)	0.36 (0.02)		
	15 May	0.36 (0.04)	0.39 (0.03)		
	Mean	**0.39 (0.02)**	**0.38 (0.01)**	**0.37**	**0.721**
Bonneville Dam	25 April	0.12 (0.02)	0.11 (0.03)		
	26 April	0.09 (0.02)	0.12 (0.04)		
	28 April	0.11 (0.02)	0.13 (0.04)		
	1 May	0.08 (0.02)	0.14 (0.03)		
	3 May	0.12 (0.03)	0.14 (0.02)		
	5 May	0.14 (0.02)	0.14 (0.03)		
	9 May	0.06 (0.02)	0.12 (0.04)		
	10 May	0.10 (0.03)	0.11 (0.03)		
	12 May	0.04 (0.02)	0.13 (0.04)		
	15 May	0.09 (0.02)	0.16 (0.04)		
	Mean	**0.10 (0.01)**	**0.13 (< 0.01)**	**3.27**	**0.010**

Survival Probability—Survival from release to all detection sites within the Snake River did not differ significantly between AT and PIT-tagged yearling Chinook salmon ($\alpha = 0.05$; Table 5). However, in the Columbia River significant differences in survival were observed from release to John Day Dam and from release to Bonneville Dam. At both of these Columbia River locations, survival was higher for PIT-tagged fish. Differences in survival generally increased with increasing distance traveled from the release site (Figure 10).

Mean survival of AT and PIT fish from release to Little Goose Dam was similar (Table 5). Additionally, no temporal trend in survival was observed between the two groups from release to Little Goose Dam (Figure 10).

AT fish from all but the last release group had a higher probability of survival from release to Lower Monumental Dam compared to PIT fish (Table 5; Figure 10). However, overall mean survival probabilities of AT and PIT fish to Lower Monumental Dam were 0.92 and 0.88, respectively, and did not differ significantly ($P = 0.080$; Table 5).

At Ice Harbor Dam, differences in survival between AT and PIT fish were inconsistent throughout the study period. For the first five release groups, survival of PIT fish was higher than that of AT fish from release to Ice Harbor Dam. This trend reversed for the last five release groups, when AT fish had a higher probability of survival compared to PIT fish. Mean survival probabilities of AT and PIT fish to Ice Harbor Dam were 0.81 and 0.84, respectively, and did not significantly differ ($P = 0.285$; Table 5).

Table 5. Mean survival probability and *t*-test results from release to downstream detection sites in the Snake River for AT and PIT river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location. Standard errors are in parentheses.

		Mean survival probability of yearling Chinook salmon from Lower Granite Dam			
Detection site	Release date	Acoustic tagged	PIT-tagged	t	*P*
Little Goose Dam	25 Apr	0.87 (0.05)	0.96 (0.03)		
	26 Apr	0.88 (0.06)	0.96 (0.03)		
	28 Apr	0.95 (0.06)	0.92 (0.03)		
	1 May	0.90 (0.06)	0.91 (0.03)		
	3 May	0.95 (0.09)	0.95 (0.03)		
	5 May	1.02 (0.09)	0.85 (0.03)		
	9 May	0.92 (0.04)	0.91 (0.02)		
	10 May	0.93 (0.04)	0.90 (0.02)		
	12 May	0.91 (0.05)	0.95 (0.02)		
	15 May	0.93 (0.05)	0.99 (0.03)		
	Mean	**0.93 (0.01)**	**0.93 (0.01)**	**0.14**	**0.893**
Lower Monumental Dam	25 Apr	0.88 (0.05)	0.85 (0.02)		
	26 Apr	0.87 (0.06)	0.82 (0.02)		
	28 Apr	0.97 (0.08)	0.88 (0.03)		
	1 May	0.84 (0.07)	0.84 (0.03)		
	3 May	1.15 (0.22)	0.94 (0.05)		
	5 May	0.90 (0.05)	0.88 (0.03)		
	9 May	0.87 (0.04)	0.84 (0.02)		
	10 May	0.92 (0.05)	0.91 (0.02)		
	12 May	1.01 (0.13)	0.93 (0.04)		
	15 May	0.82 (0.05)	0.89 (0.03)		
	Mean	**0.92 (0.03)**	**0.88 (0.01)**	**1.98**	**0.080**
Ice Harbor Dam	25 Apr	0.73 (0.02)	0.81 (0.03)		
	26 Apr	0.77 (0.07)	0.82 (0.04)		
	28 Apr	0.80 (0.07)	0.90 (0.06)		
	1 May	0.68 (0.06)	0.85 (0.06)		
	3 May	0.76 (0.10)	0.91 (0.05)		
	5 May	0.87 (0.06)	0.83 (0.03)		
	9 May	0.88 (0.10)	0.81 (0.06)		
	10 May	0.96 (0.14)	0.89 (0.06)		
	12 May	0.81 (0.12)	0.81 (0.04)		
	15 May	0.87 (0.15)	0.80 (0.07)		
	Mean	**0.81 (0.03)**	**0.84 (0.01)**	**1.14**	**0.285**

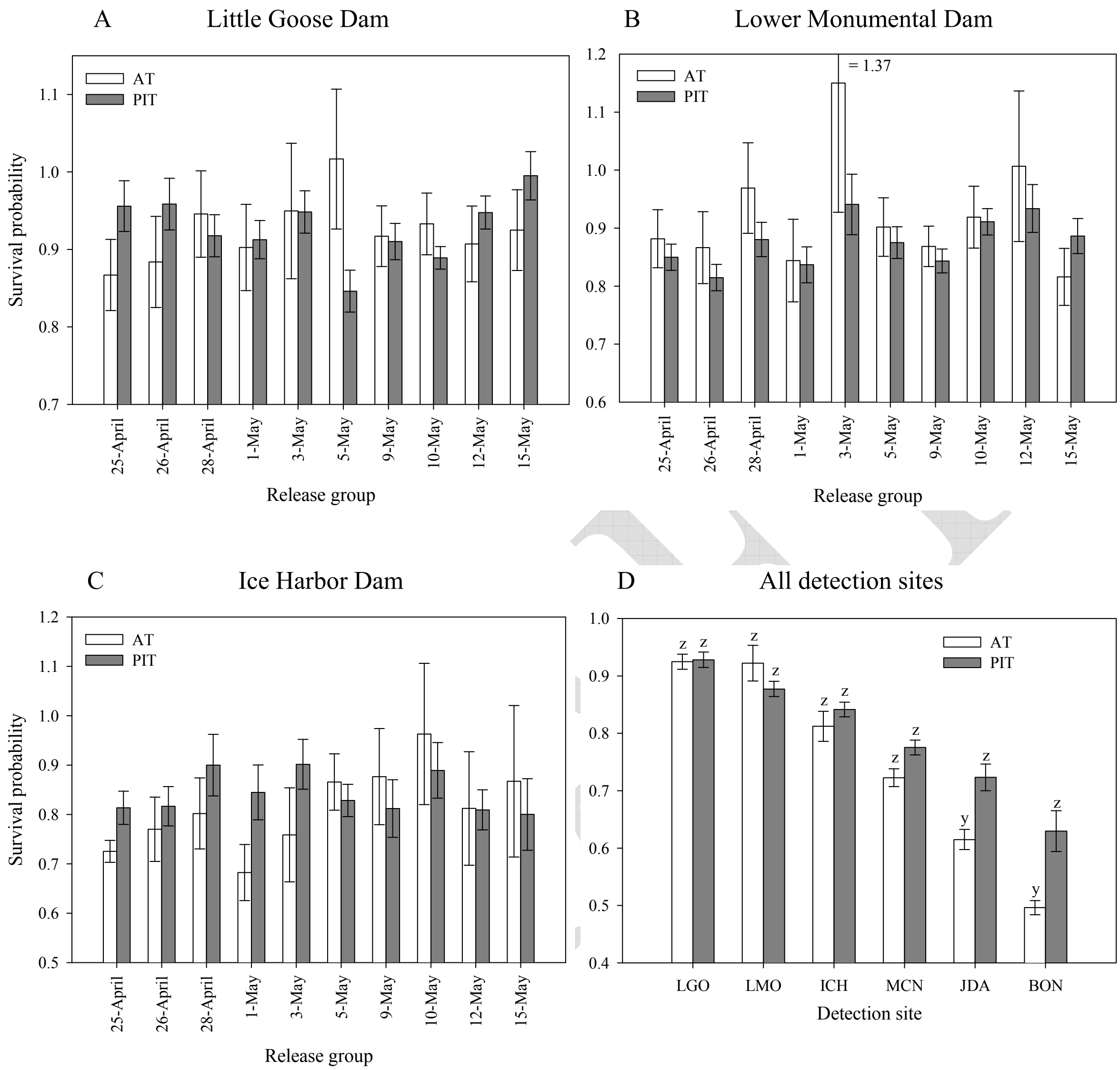


Figure 10. Mean survival probabilities by release date of AT and PIT-tagged yearling Chinook salmon from Lower Granite Dam tailrace to detection at A) Little Goose, B) Lower Monumental, C) Ice Harbor, and D) all detection sites (for the combined releases). Whisker bars denote standard errors. Dissimilar letters indicate a significant difference in estimated survival between tag treatments (α = 0.05). Abbreviations: LGO, Little Goose; LMO Lower Monumental; ICH Ice Harbor, MCN McNary, JDA John Day, BON Bonneville.

The difference in survival between AT and PIT fish from release to McNary Dam varied somewhat throughout the field season (Table 6; Figure 11A). With the exception of releases on 10 and 15 May, PIT fish had higher probabilities of survival to McNary Dam than AT fish. For fish released on 26 April and 1 and 3 May, the probability of survival was much greater for PIT than for AT fish. Overall mean survival probability to McNary Dam was 0.72 for AT and 0.78 for PIT fish, and the difference was very nearly significant ($P = 0.054$, Table 6).

The probability of survival to John Day Dam for AT and PIT yearling Chinook salmon followed a pattern similar to that observed at McNary Dam. PIT fish had a greater probability of survival for each release except the 10 and 15 May releases (Table 6, Figure 11B). Overall, PIT fish had a significantly greater survival probability (0.72) to John Day Dam than AT fish (0.62; $P = 0.001$).

When yearling Chinook salmon reached Bonneville Dam, survival was greater for PIT fish compared to AT fish for 9 of 10 release groups (Table 6; Figure 11C). Survival was greater for AT fish than PIT fish for only the 15 May release group. Overall, survival from release to Bonneville Dam was significantly greater ($P = 0.001$) for PIT fish (0.63) compared to AT fish (0.50).

Table 6. Mean survival probability and *t*-test results from release to each detection site on the Columbia River for AT and PIT tagged river-run yearling Chinook salmon released to the Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

Reach evaluated	Release date	Mean survival probability AT	Mean survival probability PIT	t	*P*
Lower Granite to McNary tailrace	25 April	0.76 (0.03)	0.81 (0.02)		
	26 April	0.70 (0.03)	0.81 (0.02)		
	28 April	0.76 (0.03)	0.76 (0.02)		
	1 May	0.65 (0.03)	0.82 (0.02)		
	3 May	0.64 (0.03)	0.83 (0.02)		
	5 May	0.77 (0.03)	0.79 (0.02)		
	9 May	0.75 (0.03)	0.75 (0.03)		
	10 May	0.78 (0.03)	0.74 (0.02)		
	12 May	0.69 (0.03)	0.73 (0.02)		
	15 May	0.74 (0.03)	0.72 (0.02)		
	Mean	**0.72 (0.02)**	**0.78 (0.01)**	**2.21***	**0.054**
Lower Granite to John Day tailrace	25 April	0.68 (0.04)	0.70 (0.03)		
	26 April	0.62 (0.03)	0.74 (0.04)		
	28 April	0.63 (0.04)	0.71 (0.04)		
	1 May	0.51 (0.04)	0.81 (0.05)		
	3 May	0.54 (0.04)	0.78 (0.03)		
	5 May	0.68 (0.04)	0.80 (0.04)		
	9 May	0.60 (0.03)	0.72 (0.05)		
	10 May	0.67 (0.05)	0.64 (0.03)		
	12 May	0.59 (0.06)	0.76 (0.05)		
	15 May	0.62 (0.05)	0.58 (0.04)		
	Mean	**0.62 (0.02)**	**0.72 (0.02)**	**3.25***	**0.010**
Lower Granite to Bonneville tailrace	25 April	0.56 (0.03)	0.79 (0.20)		
	26 April	0.52 (0.04)	0.76 (0.24)		
	28 April	0.52 (0.04)	0.55 (0.15)		
	1 May	0.47 (0.07)	0.58 (0.14)		
	3 May	0.48 (0.04)	0.63 (0.10)		
	5 May	0.53 (0.03)	0.63 (0.12)		
	9 May	0.50 (0.03)	0.71 (0.21)		
	10 May	0.52 (0.05)	0.64 (0.15)		
	12 May	0.43 (0.03)	0.61 (0.17)		
	15 May	0.45 (0.06)	0.39 (0.09)		
	Mean	**0.50 (0.01)**	**0.63 (0.04)**	**4.87***	**0.001**

A McNary Dam

B John Day Dam

C Bonneville Dam

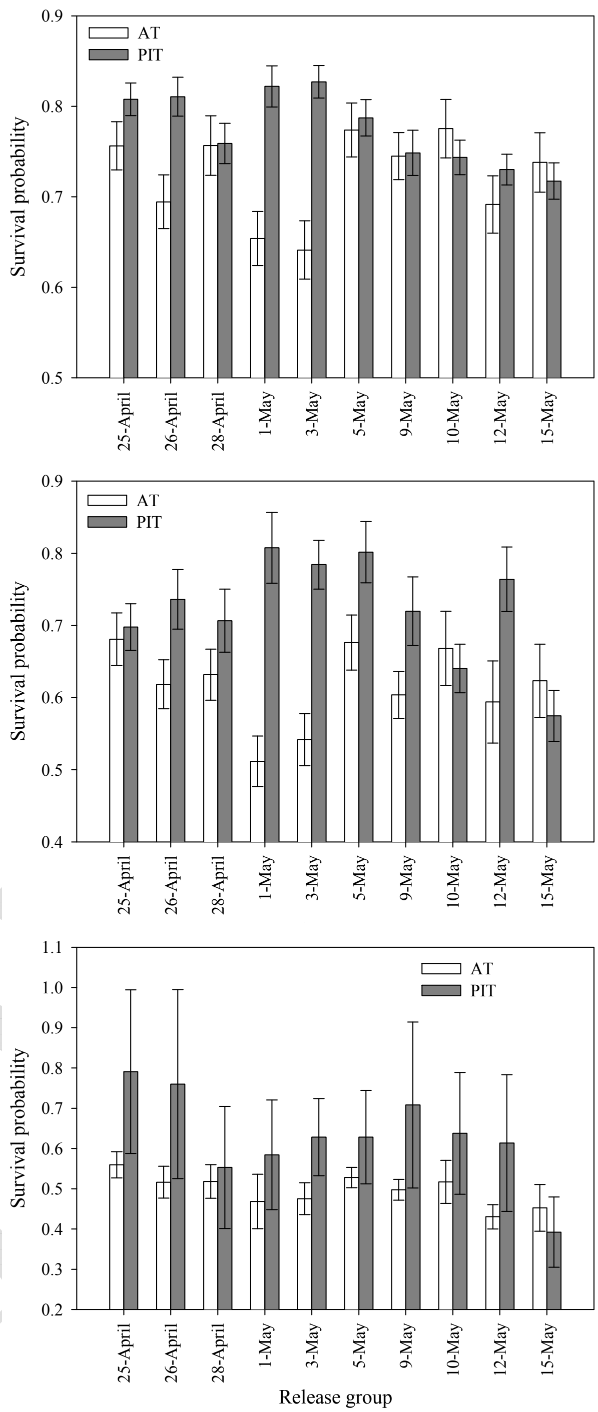


Figure 11. Mean survival probabilities of AT and PIT river-run yearling Chinook salmon from release at Lower Granite Dam to Columbia River detection sites at A) McNary, B) John Day, and C) Bonneville Dam in 2007. Whisker bars denote standard errors.

Travel Time—Median travel time to a downstream dam was calculated for each release group with 10 or more detections of yearling Chinook salmon at that dam. The greatest number of PIT-tag detections occurred at McNary Dam, where 948 AT and 13,472 PIT fish were detected throughout the season. Ten or more AT and PIT fish were detected at each hydroelectric dam from every release group with one exception: only nine AT fish from the 15 May release were detected at Ice Harbor Dam. Therefore, these data were not included in the travel time analyses.

AT fish had higher overall mean travel times from Lower Granite Dam to downstream detection sites compared to PIT fish (Figure 12); however, the only significant difference in travel time between the two groups was at John Day Dam, where AT fish took significantly ($P = 0.041$) more time to reach the dam compared to PIT fish.

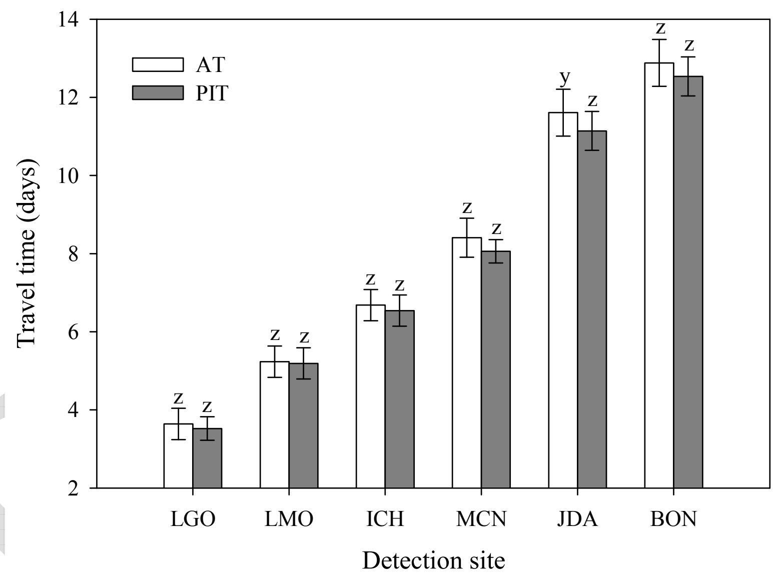


Figure 12. Mean travel time for combined release groups of AT and PIT-tagged yearling Chinook salmon from release at Lower Granite Dam to detection at downstream dams on the Snake and Columbia River, 2007. Whisker bars denote standard errors. Abbreviations: LGO, Little Goose Dam; LMO, Lower Monumental Dam; ICH, Ice Harbor Dam; MCN, McNary Dam; JDA, John Day Dam; BON, Bonneville Dam.

Based on this information, it appears that AT and PIT fish likely experienced similar operational and environmental conditions at the majority of detection locations, including all locations where detection probabilities differed significantly between groups.

Median travel times of AT and PIT release groups to Little Goose and Lower Monumental Dams followed the same general trend, and travel time appeared to be correlated with discharge ($r = 0.88$; Appendix Table F3). The first release of test fish from both tag treatment groups (24 April) had the greatest median travel time to both dams (Figures 13A and B). Median travel time decreased for each group of fish released between 24 April and 3 May, increased for each group released between 1 May and 8 May, decreased for groups released between 5 and 15 May, and increased for the final group released on 15 May. In general, the least amount of time was taken to reach these dams by fish released on 1 May and by fish released later in the season (8-15 May).

The trend observed at Ice Harbor Dam deviated slightly from the trend observed at Little Goose and Lower Monumental Dams. The first release group had the highest median travel time of any group, followed by a decrease in travel time for groups released between 24 April and 3 May (Figure 13). Travel times to Ice Harbor Dam increased for fish released on 3 May, then declined for 5 and 8 May releases. Travel times were generally lower for groups released on 28 April and 1 May, and for groups released later in the season (8–12 May).

Median travel times to each dam on the Columbia River followed a trend similar to that observed for Snake River dams. The first two release groups (24 and 26 April) experienced the longest travel times to McNary, John Day, and Bonneville Dams, followed by a decline in travel time for groups released on 28 April and 1 May (Figure 14A and 13C). Travel times remained relatively low and constant for each group of fish released from 1 to 15 May, with the exception of the 5 May release, which had slightly elevated travel times.

A Little Goose Dam

B Lower Monumental Dam

C Ice Harbor Dam

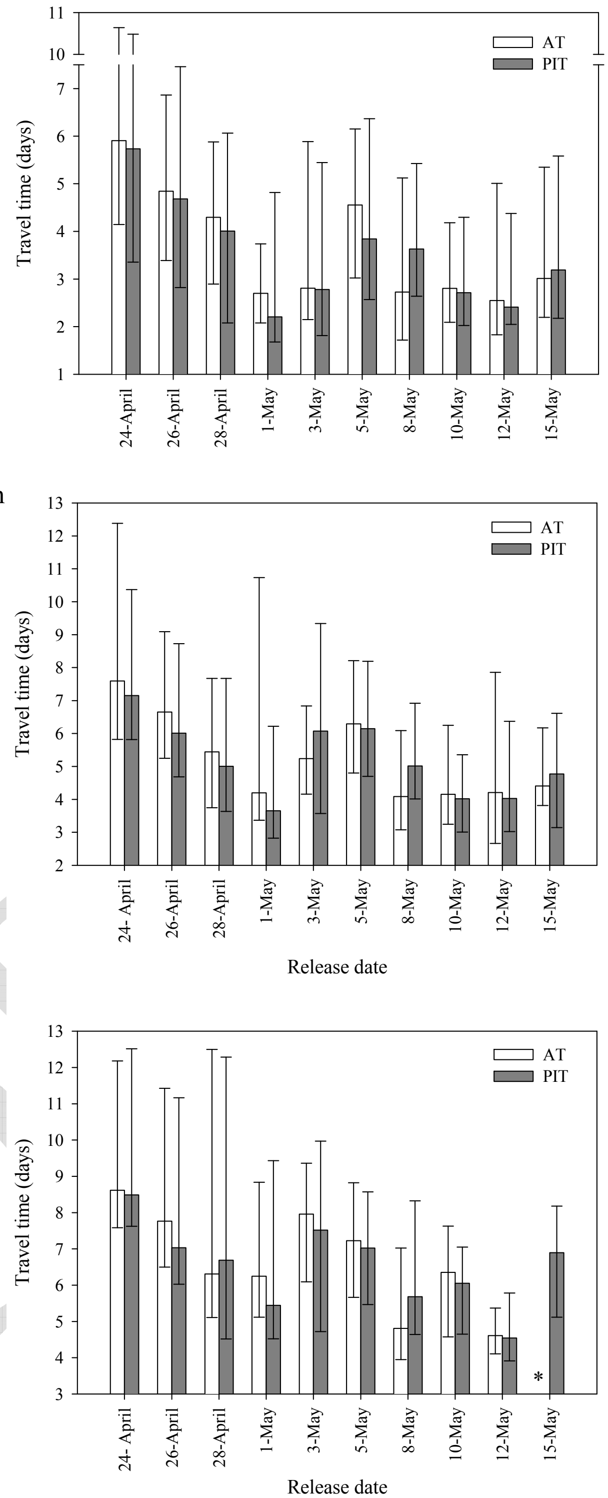
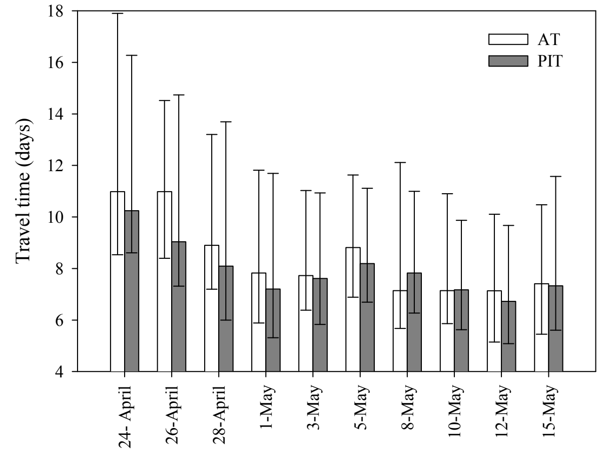
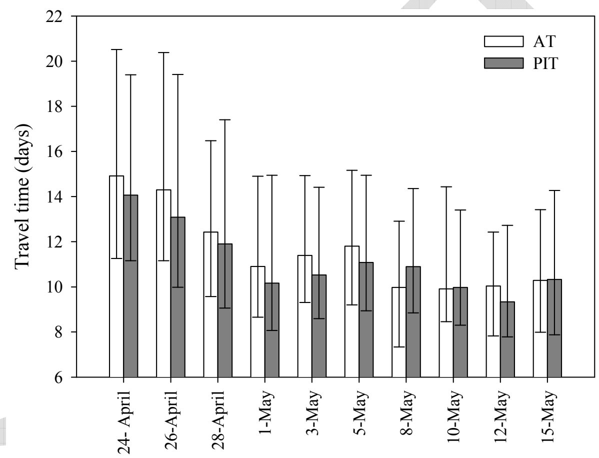


Figure 13. Median travel time to A) Little Goose, B) Lower Monumental, and C) Ice Harbor Dam on the Snake River for AT and PIT groups of yearling Chinook salmon released at Lower Granite Dam, 2007. Whisker bars denote the 10th and 90th percentiles of fish from each release group (date) arriving at each detection location.

A McNary Dam



B John Day Dam



C Bonneville Dam

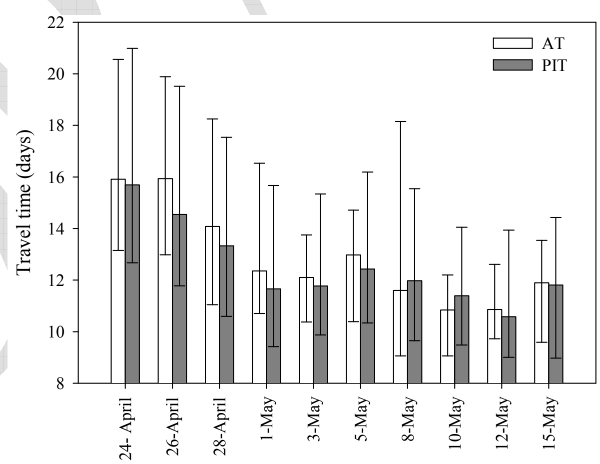


Figure 14. Median travel time to A) McNary, B) John Day, and C) Bonneville Dam on the Columbia River for AT and PIT yearling Chinook salmon release groups released at Lower Granite Dam in 2007. Whisker bars denote the 10th and 90th percentiles of fish from each release group (date) arriving at each detection location.

Avian Predation—Recoveries of PIT-tags from study fish were combined for all upriver bird colonies sampled. Upriver colonies sampled were Badger Island pelican, Crescent Island gull and tern, Foundation Island cormorant, Miller Rocks gull, Miller Sands cormorant, and Rock Island tern. Totals from the combined upriver colonies averaged 0.9% (range 0.0-1.8%) for AT releases and 1.0% (range = 0.5-1.6%) for PIT releases (Table 7).

Estuary colonies sampled were tern and cormorant colonies on East Sand Island. Total PIT-tag recoveries from all colonies on East Sand Island averaged 3.3% (range 0.8-5.5%) for AT releases and 2.7% (range 2.0-3.4%) for PIT-tagged releases.

Differences in the proportion of PIT tags recovered between AT and PIT fish groups were not significant in comparisons of either the upriver (P = 0.500) or estuarine bird colonies (P = 0.243). Percentages of PIT tags recovered by individual colony and colony location were also similar between the two treatments (Table 8). These analyses were based on actual PIT detections and were not adjusted for detection efficiency rates. Since detection efficiency rates are not 100%, the estimates shown in Tables 7 and 8 represent minimum estimates of predation.

Table 7. Percentages of yearling Chinook PIT tags recovered from upriver and estuarine bird colonies in the Columbia River by tag treatment and release date. The actual number of tags recovered by colony is listed in parentheses.

Release date	Upriver bird colonies (%)	SE	Estuarine bird colonies (%)	SE	Overall from release (%)
			AT Yearling Chinook		
25 Apr	0.0 (0)	NA	3.5 (8)	1.2	2.0 (8)
26 Apr	0.9 (3)	0.5	3.4 (7)	1.3	2.5 (10)
28 Apr	1.8 (7)	0.7	2.4 (5)	1.1	3.0 (12)
1 May	0.9 (3)	0.5	3.7 (7)	1.5	3.5 (14)
3 May	0.0 (0)	NA	2.1 (4)	1.0	1.7 (7)
5 May	1.9 (7)	0.7	3.2 (7)	1.2	3.4 (14)
9 May	1.4 (5)	0.6	5.5 (11)	1.6	4.0 (16)
10 May	0.8 (2)	0.6	5.0 (7)	1.9	3.3 (9)
12 May	0.0 (0)	NA	0.8 (1)	0.8	0.7 (2)
15 May	0.7 (2)	0.5	3.0 (5)	1.4	1.9 (7)
Overall	0.9 (29)	0.2	3.3 (62)	0.3	2.6 (99)
			PIT Yearling Chinook		
25 Apr	0.5 (18)	0.1	2.2 (79)	0.6	2.2 (97)
26 Apr	0.8 (26)	0.2	2.0 (58)	0.7	2.2 (84)
28 Apr	0.9 (25)	0.2	3.4 (63)	1.0	2.6 (88)
1 May	1.1 (34	0.2	3.2 (71)	0.8	2.8 (105)
3 May	0.9 (68)	0.1	2.3 (117)	0.4	2.3 (185)
5 May	0.9 (43)	0.1	2.9 (102)	0.6	2.6 (145)
9 May	1.4 (43)	0.2	2.5 (63)	0.8	3.0 (106)
10 May	0.9 (40)	0.1	3.4 (104)	0.9	3.0 (144)
12 May	1.0 (43)	0.2	2.7 (79)	0.8	2.5 (122)
15 May	1.6 (63)	0.2	2.4 (44)	0.7	2.3 (107)
Overall	1.0 (403)	0.0	2.7 (78)	0.1	2.5 (1183)
Mean difference (AT-PIT)	-0.2		0.5		
SE	0.2		0.4		
t	-0.70		1.25		
P	0.500		0.243		

Table 8. Percentages of PIT tags from AT and PIT-tagged yearling Chinook salmon that were subsequently recovered on avian predator colonies in 2007 by colony location, tag treatment, and release date. Numbers of tags recovered are shown in parentheses.

Release date	Badger Island	Crescent Island		Foundation Isl	Miller Rocks	Miller Sands	Rock Island	East Sand Island	
	Pelican	Gull	Tern	Cormorant	Gull	Cormorant	Tern	Cormorant	Tern
	Percent (%) and number (n) from AT river-run yearling Chinook salmon								
25 Apr	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	3.1 (7)
26 Apr	0.0 (0)	0.3 (1)	0.3 (1)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	3.4 (7)
28 Apr	0.0 (0)	0.0 (0)	0.5 (2)	0.8 (3)	0.0 (1)	0.0 (0)	0.3 (1)	0.0 (0)	2.4 (5)
1 May	0.0 (0)	0.0 (0)	0.6 (2)	0.6 (2)	0.0 (1)	0.0 (0)	0.3 (1)	0.0 (0)	4.2 (8)
3 May	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)	0.0 (0)	0.0 (0)	1.0 (2)	2.1 (4)
5 May	0.0 (0)	0.0 (0)	0.3 (1)	1.6 (6)	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (2)	2.3 (5)
9 May	0.0 (0)	0.6 (2)	0.0 (0)	0.9 (3)	0.0 (0)	0.0 (0)	0.0 (0)	2.0 (4)	3.5 (7)
10 May	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (1)	0.0 (0)	0.0 (0)	1.4 (2)	3.5 (5)
12 May	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (1)
15 May	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (1)	2.4 (4)
Overall	0.0 (0)	0.1 (3)	0.2 (6)	0.6 (19)	4 (0.1)	0.0 (0)	0.1 (2)	0.6 (12)	2.8 (53)
	Percent (%) and number (n) of tags from PIT river-run yearling Chinook salmon								
25 Apr	0.0 (0)	0.0 (0)	0.1 (3)	0.2 (6)	4 (0.1)	0.1 (3)	0.1 (2)	0.3 (11)	1.9 (68)
26 Apr	0.0 (0)	0.2 (5)	0.0 (1)	0.4 (11)	5 (0.2)	0.0 (1)	0.1 (3)	0.2 (5)	1.9 (53)
28 Apr	0.0 (0)	0.1 (3)	0.2 (6)	0.3 (10)	3 (0.1)	0.0 (1)	0.1 (2)	0.3 (6)	3.1 (57)
1 May	0.0 (1)	0.1 (3)	0.1 (2)	0.6 (18)	5 (0.2)	0.0 (1)	0.1 (4)	0.6 (14)	2.6 (57)
3 May	0.0 (1)	0.1 (9)	0.1 (10)	0.4 (30)	13 (0.2)	0.0 (3)	0.0 (2)	0.3 (17)	2.0 (100)
5 May	0.0 (1)	0.1 (3)	0.0 (2)	0.6 (29)	6 (0.1)	0.0 (0)	0.0 (2)	0.9 (31)	2.0 (71)
9 May	0.1 (2)	0.1 (4)	0.1 (4)	1.1 (32)	1 (0.0)	0.0 (0)	0.0 (0)	0.6 (15)	1.9 (48)
10 May	0.0 (0)	0.0 (3)	0.2 (7)	0.5 (21)	5 (0.1)	0.1 (2)	0.1 (2)	1.5 (46)	1.9 (58)
12 May	0.1 (3)	0.0 (4)	0.1 (5)	0.4 (19)	8 (0.1)	0.0 (2)	0.0 (2)	0.9 (26)	1.8 (53)
15 May	0.0 (0)	0.1 (4)	0.2 (6)	1.1 (43)	8 (0.1)	0.0 (0)	0.1 (2)	0.3 (6)	2.1 (38)
Overall	0.0 (8)	0.1 (38)	0.1 (46)	0.5 (219)	58 (0.1)	0.0 (13)	0.1 (21)	0.6 (177)	2.1 (603)

Subyearling Chinook Salmon

Detection Probability—For subyearling Chinook salmon in 2007, totals of 7,736 AT fish and 26,415 PIT fish were released to the tailrace of Lower Granite Dam. Of these fish, there were 2,241, and 11,570 first-time PIT-tag detections of AT and PIT fish, respectively, at downstream dams on the Snake and Columbia Rivers (Appendix D). PIT-tag detection probabilities varied among release groups and detection locations (Figure 15; Tables 9-10).

Mean detection probabilities were relatively high at Little Goose Dam, with detection rates of 0.33 for AT fish and 0.22 for PIT fish. Detection rates were similarly high at McNary Dam (Table 10). However, too few detections occurred at all remaining locations to calculate reliable estimates of detection or survival. For the AT pilot subyearling fish, detection rates were insufficient at all downstream detection locations to calculate reliable estimates.

Mean detection probability was significantly higher for AT than for PIT-tagged subyearling Chinook at Little Goose Dam (*P* = 0.001) but was similar between tag treatments at McNary Dam (*P* = 0.505) (Figure 15; Tables 9-10).

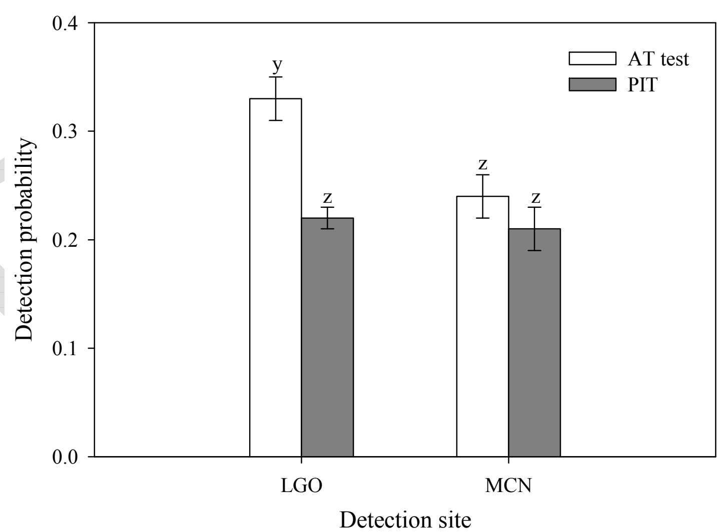


Figure 15. Mean PIT tag detection probability of AT and PIT-tagged subyearling Chinook salmon at Little Goose (LGO) and McNary (MCN) Dams in 2007. Error bars denote standard errors. Dissimilar letters indicate a significant difference between groups at a detection site (α = 0.05).

Table 9. Mean PIT-tag detection probability and *t*-test results at Little Goose Dam for AT and PIT subyearling Chinook salmon released to Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate.

		Mean detection probability at Little Goose Dam for subyearling Chinook salmon	
Release date		AT fish	PIT fish
5 June		0.26 (0.04)	0.16 (0.02)
6 June		0.32 (0.05)	0.27 (0.02)
7 June		0.34 (0.05)	0.27 (0.02)
8 June		0.30 (0.07)	0.26 (0.02)
9 June		0.34 (0.06)	0.30 (0.03)
12 June		0.47 (0.07)	0.21 (0.03)
13 June		0.49 (0.08)	0.27 (0.03)
14 June		0.37 (0.07)	0.23 (0.03)
15 June		0.30 (0.06)	0.26 (0.03)
16 June		0.33 (0.08)	0.23 (0.03)
19 June		0.31 (0.05)	0.17 (0.02)
20 June		0.23 (0.07)	0.17 (0.03)
21 June		0.17 (0.06)	0.15 (0.03)
22 June		0.24 (0.06)	0.13 (0.03)
23 June		0.12 (0.05)	0.13 (0.03)
26 June		0.44 (0.07)	0.20 (0.02)
27 June		0.21 (0.07)	0.21 (0.03)
28 June		0.28 (0.11)	0.22 (0.03)
29 June		0.41 (0.09)	0.23 (0.06)
30 June		0.44 (0.10)	0.22 (0.04)
3 July		0.42 (0.09)	0.27 (0.04)
4 July		0.29 (0.10)	0.25 (0.05)
5 July		0.28 (0.14)	0.37 (0.06)
6 July		0.40 (0.22)	0.24 (0.03)
12 July		0.33 (0.12)	0.21 (0.08)
13 July		0.50 (0.25)	0.10 (0.09)
14 July		*	0.32 (0.09)
Mean		0.33 (0.02)	0.22 (0.01)
t	3.73		
P	0.001		

Table 10. Mean PIT tag detection probability and *t*-test results at McNary Dam (MCN) for AT and PIT-tagged subyearling Chinook salmon released to Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate.

Release date	Mean detection probability at McNary Dam for subyearling Chinook salmon	
	AT fish	PIT fish
5 June	0.46 (0.05)	0.27 (0.03)
6 June	0.35 (0.05)	0.36 (0.03)
7 June	0.28 (0.05)	0.28 (0.03)
8 June	0.26 (0.06)	0.28 (0.03)
9 June	0.26 (0.05)	0.26 (0.03)
12 June	0.22 (0.06)	0.18 (0.04)
13 June	0.22 (0.07)	0.17 (0.03)
14 June	0.18 (0.06)	0.24 (0.04)
15 June	0.22 (0.06)	0.14 (0.03)
16 June	0.29 (0.08)	0.16 (0.03)
19 June	0.29 (0.06)	0.21 (0.04)
20 June	0.28 (0.08)	0.23 (0.05)
21 June	0.16 (0.06)	0.18 (0.04)
22 June	0.42 (0.07)	0.15 (0.04)
23 June	0.29 (0.06)	0.12 (0.03)
26 June	0.15 (0.05)	0.28 (0.04)
27 June	0.28 (0.08)	0.20 (0.04)
28 June	0.38 (0.12)	0.24 (0.05)
29 June	0.07 (0.05)	0.13 (0.07)
30 June	0.13 (0.07)	0.24 (0.06)
3 July	0.14 (0.06)	0.16 (0.04)
4 July	0.16 (0.08)	0.22 (0.06)
5 July	0.20 (0.13)	0.21 (0.07)
6 July	0.20 (0.18)	0.16 (0.04)
12 July	0.07 (0.07)	0.05 (0.05)
13 July	0.25 (0.22)	0.50 (0.20)
14 July	*	0.18 (0.09)
Mean	0.24 (0.02)	0.21 (0.02)
t	0.68	
P	0.505	

Survival Probability—Survival of PIT-tagged subyearling Chinook salmon was significantly greater than that of AT subyearling Chinook salmon from release at Lower Granite Dam to both Little Goose ($P = 0.003$) and McNary Dam ($P = 0.001$; Tables 11-12; Figure 16). Survival decreased from Little Goose to McNary Dam, but the difference in overall survival probability between tag treatments was greater from Lower Granite to McNary than from Lower Granite to Little Goose Dam (Figure 16).

Temporally, survival probability varied much less from the first release date (5 June) until the end of June for both AT and PIT fish than it did towards the end of the season. During the end of the season, a general trend of decreased survival probability through time for AT fish was apparent. At Little Goose Dam, this trend began with the 5 July release group and continued through the study period (Table 11; Figure 17). This trend of decreasing survival through time was observed for both AT and PIT fish at McNary Dam, beginning with the 30 June release group and continuing through the remainder of the study period (Table 12; Figure 18).

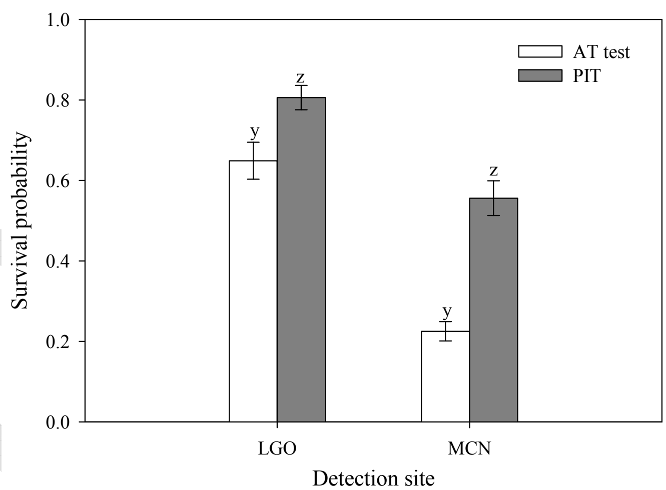


Figure 16. Survival probability of AT and PIT subyearling Chinook salmon between release in the tailrace of Lower Granite Dam to Little Goose (LGO) and McNary (MCN) Dams in 2007. Error bars denote standard errors. Dissimilar letters above pairs of bars indicate significant difference ($\alpha = 0.05$) between groups at each detection site.

Table 11. Mean survival probability and *t*-test results for AT and PIT subyearling Chinook from release at Lower Granite Dam to Little Goose Dam in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

	Mean survival probability at Little Goose Dam for subyearling Chinook salmon	
Release date	AT fish	PIT-tagged fish
5 June	0.79 (0.09)	0.98 (0.09)
6 June	0.76 (0.08)	0.78 (0.05)
7 June	0.91 (0.10)	0.82 (0.05)
8 June	0.86 (0.17)	0.85 (0.07)
9 June	0.76 (0.11)	0.77 (0.06)
12 June	0.75 (0.11)	0.95 (0.11)
13 June	0.55 (0.08)	0.90 (0.08)
14 June	0.68 (0.12)	0.96 (0.11)
15 June	0.91 (0.18)	0.80 (0.09)
16 June	0.73 (0.16)	0.82 (0.08)
19 June	0.59 (0.09)	1.02 (0.13)
20 June	0.64 (0.18)	0.76 (0.12)
21 June	0.82 (0.26)	0.82 (0.14)
22 June	0.67 (0.14)	0.78 (0.15)
23 June	1.24 (0.44)	0.75 (0.13)
26 June	0.40 (0.05)	0.79 (0.09)
27 June	0.74 (0.22)	0.69 (0.08)
28 June	0.46 (0.16)	0.73 (0.09)
29 June	0.44 (0.08)	0.62 (0.14)
30 June	0.42 (0.09)	0.79 (0.13)
3 July	0.49 (0.10)	0.68 (0.09)
4 July	0.80 (0.26)	1.04 (0.18)
5 July	0.64 (0.30)	0.51 (0.08)
6 July	0.51 (0.27)	0.91 (0.12)
12 July	0.24 (0.08)	0.77 (0.27)
13 July	0.08 (0.04)	1.11 (1.04)
14 July	*	0.40 (0.10)
Mean	0.65 (0.05)	0.81 (0.03)
$t = 3.30$		
$P = 0.003$		

Table 12. Mean survival probability and *t*-test results for AT and PIT subyearling Chinook salmon from release at Lower Granite Dam to McNary Dam in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

	Mean survival probability at McNary Dam for subyearling Chinook salmon	
Release date	AT fish	PIT-tagged fish
5 June	0.47 (0.04)	0.86 (0.09)
6 June	0.40 (0.04)	0.75 (0.06)
7 June	0.45 (0.05)	0.81 (0.09)
8 June	0.23 (0.04)	0.65 (0.07)
9 June	0.36 (0.05)	0.59 (0.07)
12 June	0.24 (0.05)	0.68 (0.12)
13 June	0.22 (0.05)	0.71 (0.11)
14 June	0.26 (0.07)	0.51 (0.07)
15 June	0.25 (0.05)	0.75 (0.16)
16 June	0.22 (0.05)	0.73 (0.13)
19 June	0.31 (0.04)	0.58 (0.09)
20 June	0.19 (0.04)	0.45 (0.08)
21 June	0.23 (0.06)	0.59 (0.12)
22 June	0.21 (0.03)	0.75 (0.20)
23 June	0.22 (0.04)	0.84 (0.20)
26 June	0.33 (0.09)	0.47 (0.06)
27 June	0.21 (0.05)	0.60 (0.11)
28 June	0.08 (0.02)	0.49 (0.09)
29 June	0.39 (0.23)	0.91 (0.47)
30 June	0.19 (0.08)	0.47 (0.11)
3 July	0.16 (0.05)	0.43 (0.11)
4 July	0.11 (0.04)	0.33 (0.07)
5 July	0.06 (0.03)	0.26 (0.08)
6 July	0.04 (0.02)	0.42 (0.10)
12 July	0.05 (0.04)	0.27 (0.25)
13 July	0.01 (0.01)	0.03 (0.01)
14 July	*	0.10 (0.05)
Mean	0.23 (0.02)	0.56 (0.04)
$t = 21.05$		
$P \leq 0.001$		

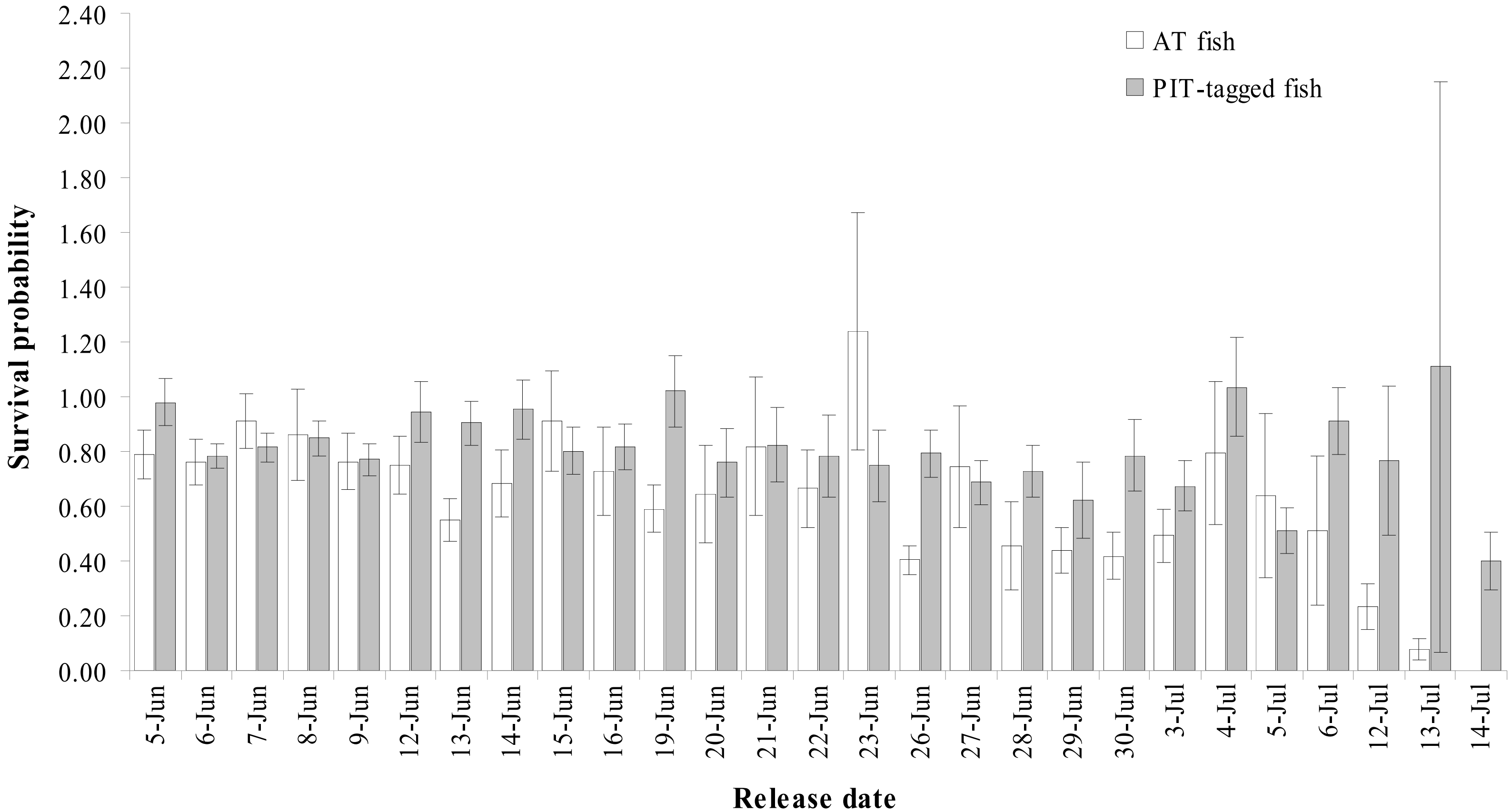


Figure 17. Survival probability of AT and PIT subyearling Chinook salmon from release at Lower Granite Dam to Little Goose Dam by release group in 2007. Error bars denote standard errors. For fish released on 14 July, the number of AT fish detected after release was too low to calculate an estimate.

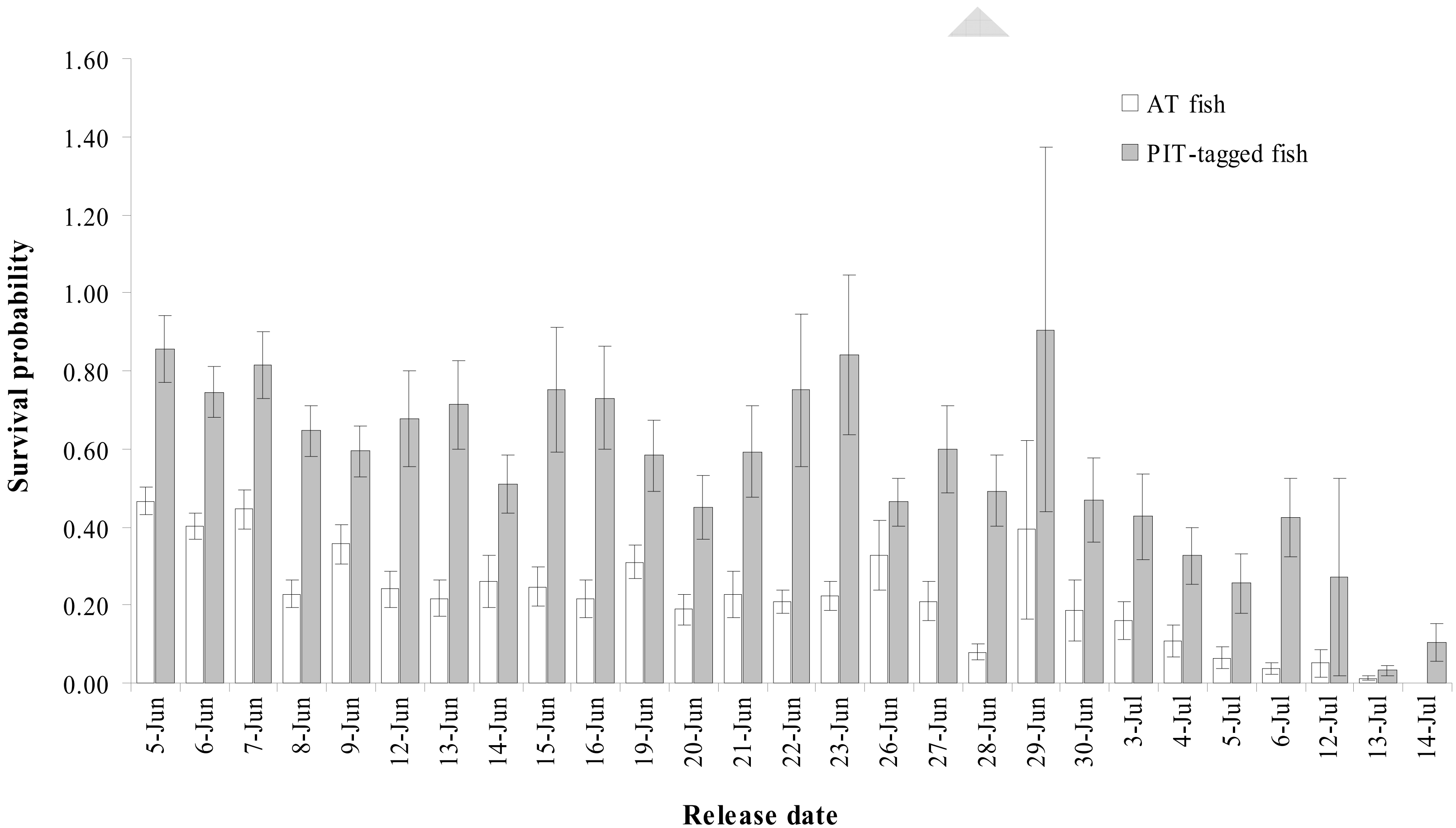


Figure 18. Survival probability of AT and PIT subyearling Chinook salmon from release at Lower Granite Dam to McNary Dam by release group in 2007. Error bars denote standard errors. For fish released on 14 July, the number of AT fish detected after release was too low to calculate an estimate.

Travel Time—Average travel time of subyearling Chinook salmon from release to each downstream detection site was significantly longer for AT than for PIT-tagged fish (P <0.05; Figure 19). These differences were as large as 1.2 d to Little Goose Dam, 1.7 d to Lower Monumental Dam, 5.2 d to Ice Harbor Dam, and 2.7 d to McNary Dam (Figure 19). Travel times were consistently longer for AT fish compared to PIT fish through time.

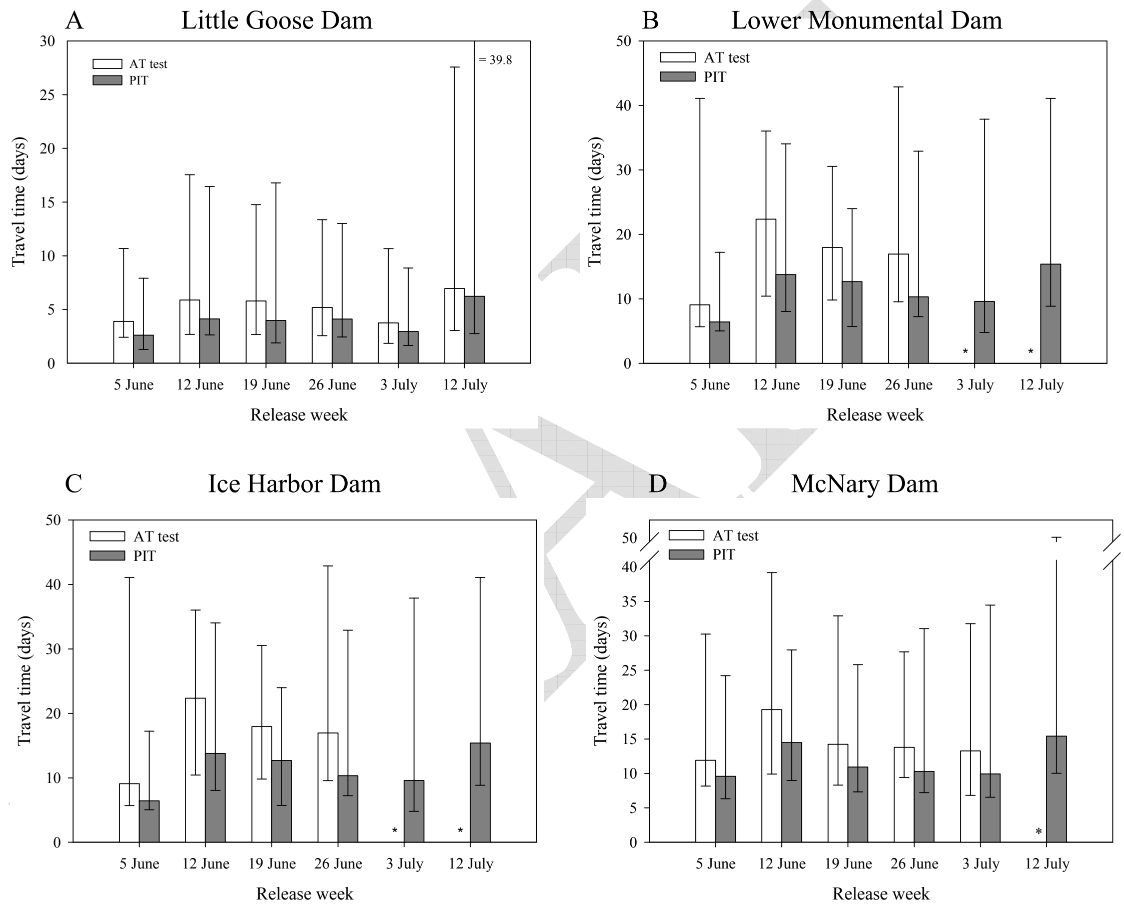


Figure 19. Median travel time of AT and PIT subyearling Chinook by week of release at Lower Granite Dam to detection at A) Little Goose B) Lower Monumental, C) Ice Harbor, and D) McNary Dams. Error bars represent 10th and 90th percentile of fish arriving at each detection location. Asterisk denotes release group where detections were too low after release to calculate an estimate.

Avian Predation—For subyearling Chinook released before 30 June, PIT-tag recovery from combined upriver bird colonies, averaged 1.3% (range 0.0-4.6%) for AT groups and 1.7% (range 0.2-2.5%) for PIT-tagged groups (Table 13). Upriver colonies sampled were the Badger Island pelican, Crescent Island gull and tern, Foundation Island cormorant, Miller Rocks gull, Miller Sands cormorant, and Rock Island tern colonies. For subyearling Chinook released before 30 June, PIT-tag recovery from the estuarine tern and cormorant colonies on East Sand Island averaged 2.5% (range 0.0-6.6%) for AT groups and 2.0% (range 0.0-6.8%) for PIT-tagged groups (Table 13).

Differences in the proportion of PIT tags recovered from AT and PIT-tagged groups were not significant in recoveries from either the upriver (P = 0.254) or estuarine colonies (P = 0.389; Table 13). Percentages of PIT tags recovered by individual colony and location were similar between the two tag treatments (Table 14). These analyses were based on actual PIT-tag detections and were not expanded by detection efficiency rates. Because detection efficiencies are less than 100%, the estimates shown in Tables 13-14 represent minimum estimates of predation.

Table 13. Percentages of PIT tags from AT and PIT-tagged fish recovered on upriver and estuarine bird colonies in the Columbia River by date of release. Actual number of tags detected is reported in parentheses. NA denotes missing or incalculable values.

Release date	Upriver bird colonies	SE	Estuarine bird colonies	SE	Overall (from release)
			AT fish		
5 June	3.4 (7)	1.3	4.2 (3)	2.5	3.8 (10)
6 June	3.9 (8)	1.4	1.0 (1)	1.0	3.4 (9)
7 June	4.6 (11)	1.4	2.7 (2)	1.9	4.9 (13)
8 June	0.4 (1)	0.4	0.0 (0)	NA	0.4 (1)
9 June	1.4 (3)	0.9	4.8 (3)	3.1	2.2 (6)
12 June	1.0 (2)	0.7	4.1 (3)	2.7	1.9 (5)
13 June	0.7 (1)	0.7	0.0 (0)	NA	0.4 (1)
14 June	0.5 (1)	0.5	4.4 (1)	4.4	0.6 (2)
15 June	0.3 (1)	0.3	3.2 (2)	2.9	0.9 (3)
16 June	1.0 (2)	0.7	4.2 (1)	4.3	1.1 (3)
19 June	0.5 (1)	0.5	1.9 (1)	2.0	0.6 (2)
20 June	1.3 (2)	0.9	0.0 (0)	NA	0.8 (2)
21 June	0.4 (1)	0.5	0 (NA)	NA	0.4 (1)
22 June	1.9 (4)	1.0	0.0 (0)	NA	1.3 (4)
23 June	1.1 (4)	0.7	0.0 (0)	NA	1.3 (4)
26 June	0.7 (1)	0.7	0.0 (0)	NA	0.3 (1)
27 June	0.5 (1)	0.6	4.4 (1)	4.4	0.8 (2)
28 June	0.8 (1)	0.9	4.1 (1)	5.2	0.7 (2)
29 June	0.9 (1)	0.9	6.6 (1)	6.6	0.8 (2)
30 June	0.0 (0)	NA	0.0 (0)	NA	0.0 (0)

Table 13. Continued.

Release date	Upriver Bird Colonies	SE	Estuarine Bird Colonies	SE	Overall (from release)
			AT fish (continued)		
3 July	0.0 (0)	NA	NA (1)	NA	0.4 (1)
4 July	0.0 (0)	NA	0 (0)	NA	0.0 (0)
5 July	0.0 (0)	NA	NA (0)	NA	0.0 (0)
6 July	2.9 (2)	2.5	NA (0)	NA	1.5 (2)
12 July	0.0 (0)	NA	NA (0)	NA	0.0 (0)
13 July	3.8 (1)	4.2	0.0 (0)	NA	0.3 (1)
14 July	0.0 (0)	NA	0.0 (0)	NA	0.0 (0)
Overall	1.2 (56)	0.2	2.2 (21)	0.2	1.0 (77)
			PIT tagged fish		
5 June	1.7 (18)	0.4	3.1 (15)	0.9	3.0 (33)
6 June	1.7 (15)	0.4	2.2 (14)	0.7	2.5 (29)
7 June	2.5 (23)	0.5	2.1 (13	0.7	3.2 (36)
8 June	1.8 (16)	0.5	1.8 (12)	0.6	2.6 (28)
9 June	2.0 (17)	0.5	1.8 (10)	0.7	2.4 (27)
12 June	1.5 (15)	0.4	2.1 (13)	1.0	2.6 (28)
13 June	1.9 (20)	0.5	1.5 (10)	0.6	2.6 (30)
14 June	2.0 (21)	0.5	1.3 (7)	0.6	2.6 (28)
15 June	1.8 (13)	0.5	0.9 (5)	0.5	2.0 (18)
16 June	1.7 (17)	0.4	1.3 (9)	0.6	2.1 (26)
19 June	1.4 (18)	0.4	1.0 (11)	0.5	2.4 (29)
20 June	1.7 (12)	0.6	3.9 (9)	1.6	2.3 (21)
21 June	1.5 (10)	0.5	1.9 (4)	1.0	1.7 (14)
22 June	1.5 (9)	0.6	1.1 (4)	0.7	1.7 (13)
23 June	2.0 (15)	0.6	3.0 (12)	1.2	2.7 (27)
26 June	1.2 (13)	0.3	1.2 (6)	0.6	1.3 (19)
27 June	1.0 (8)	0.4	1.0 (5)	0.6	1.1 (13)
28 June	1.0 (7)	0.4	0.9 (5)	0.6	1.2 (12)
29 June	1.6 (3)	1.0	6.8 (3)	4.6	2.0 (6)
30 June	0.8 (4)	0.4	1.5 (2)	1.1	1.0 (6)
3 July	0.7 (5)	0.3	0.5 (3)	0.4	0.7 (8)
4 July	0.4 (3)	0.3	4.6 (8)	2.4	1.7 (11)
5 July	0.6 (2)	0.5	6.2 (5)	3.5	1.2 (7)
6 July	0.4 (5)	0.2	4.9 (14)	2.1	1.3 (19)
12 July	0.2 (1)	0.2	0.0 (0)	NA	0.1 (1)
13 July	0.2 (1)	0.3	NA (1)	NA	0.5 (2)
14 July	0.3 (1)	0.3	0.0 (0)	NA	0.1 (1)
Overall	0.1 (292)	0.1	2.0 (200)	0.2	1.9 (492)
			Mean difference (AT-PIT) through 29 Jun 2007		
Mean Difference	-0.3				0.5
SE	0.003				0.005
t	-1.18				0.88
P	0.254				0.389

Table 14. Percent of PIT tags recovered from upriver avian predator colonies by bird species and location, treatment, and release date. The actual number of tags recovered by colony is listed in parentheses.

Release date	Badger Island	Crescent Island			Foundation Island	Ice Harbor Tail	Miller Rocks	Miller Sands	Potholes	Rock Island
	Pelican	Gull	Mixed	Tern	Cormorant	Mixed	Gull	Cormorant	Tern	Tern
					AT fish					
5 June	0.5 (1)	1.0 (2)	0.0 (0)	1.0 (2)	1.0 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 June	0.0 (0)	0.0 (0)	0.0 (0)	2.0 (4)	2.0 (4)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
7 June	0.0 (0)	0.0 (0)	0.0 (0)	1.3 (3)	2.9 (7)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)
8 June	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
9 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	1.0 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
12 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 June	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
15 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
16 June	0.5 (1)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
19 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)
20 June	0.6 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
21 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
22 June	0.0 (0)	0.5 (1)	0.0 (0)	0.9 (2)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
23 June	0.3 (1)	0.5 (2)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
26 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
27 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
28 June	0.0 (0)	0.8 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
29 June	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
30 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
3 July	0.0 (0)	0.0 (0)	0.7 (1)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
4 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
5 July	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 July	0.0 (0)	1.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.1 (4)	0.2 (8)	0.0 (1)	0.4 (20)	0.5 (21)	0.1 (3)	0.0 (1)	0.0 (0)	0.0 (0)	0.0 (1)

Table 14. Continued.

Release	Badger Island	Crescent Island		Foundation Island		Ice Harbor Tail	Miller Rocks	Miller Sands	Potholes	Rock Island
date	Pelican	Gull	Mixed	Tern	Cormorant	Mixed	Gull	Cormorant	Tern	Tern
					PIT fish					
5 June	0.1 (1)	0.1 (1)	0.0 (0)	0.4 (4)	0.6 (6)	0.0 (0)	0.5 (5)	0.0 (1)	0.0 (0)	0.0 (0)
6 June	0.0 (0)	0.1 (1)	0.0 (0)	0.4 (4)	1.1 (10)	0.0 (0)	0.0)0)	0.0 (0)	0.0 (0)	0.0 (0)
7 June	0.0 (0)	0.1 (1)	0.0 (0)	0.5 (5)	1.4 (13)	0.0 (0)	0.4 (4)	0.0 (0)	0.0 (0)	0.0 (0)
8 June	0.1 (1)	0.1 (1)	0.0 (0)	0.4 (4)	0.8 (7)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (1)
9 June	0.0 (0)	0.3 (3)	0.0 (0)	0.5 (4)	0.9 (8)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (0)
12 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (5)	0.3 (3)	0.0 (0)	0.7 (7)	0.0 (0)	0.0 (0)	0.0 (0)
13 June	0.1 (1)	0.2 (2)	0.0 (0)	0.8 (8)	0.3 (3)	0.0 (0)	0.6 (6)	0.0 (0)	0.0 (0)	0.0 (0)
14 June	0.1 (1)	0.2 (2)	0.0 (0)	1.1 (11)	0.2 (2)	0.0 (0)	0.4 (4)	0.0 (0)	0.1 (1)	0.0 (0)
15 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (5)	0.6 (4)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.0 (0)
16 June	0.1 (1)	0.3 (3)	0.0 (0)	0.8 (8)	0.2 (2)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (1)
19 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (9)	0.3 (4)	0.0 (0)	0.2 (3)	0.0 (0)	0.0 (0)	0.0 (1)
20 June	0.0 (0)	0.3 (2)	0.0 (0)	0.9 (6)	0.4 (3)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
21 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (5)	0.3 (2)	0.0 (0)	0.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)
22 June	0.0 (0)	0.2 (1)	0.0 (0)	0.5 (3)	0.3 (2)	0.0 (0)	0.5 (3)	0.0 (0)	0.0 (0)	0.0 (0)
23 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (4)	0.9 (7)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.0 (1)
26 June	0.2 (2)	0.3 (3)	0.0 (0)	0.6 (7)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
27 June	0.3 (2)	0.1 (1)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (1)	0.0 (0)	0.0 (0)
28 June	0.0 (0)	0.3 (2)	0.1 (1)	0.4 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
29 June	0.0 (0)	1.0 (2)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
30 June	0.0 (0)	0.4 (2)	0.0 (0)	0.2 (1)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
3 July	0.1 (1)	0.3 (2)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
4 July	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
5 July	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 July	0.0 (0)	0.1 (1)	0.0 (0)	0.2 (2)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.1 (11)	0.2 (33)	0.0 (1)	0.5 (108)	0.4 (81)	0 (0.0)	0.2 (51)	0.0 (2)	0.0 (1)	0.0 (4)

Table 15. Percentage of AT and PIT subyearling Chinook salmon by release date with PIT tags recovered on East Sand Island tern and cormorant colonies. Numbers of tags recovered are shown in parentheses.

	Percentage (%) and number (n) of PIT tags found on East Sand Island from AT and PIT subyearling Chinook salmon			
	Cormorant		Tern	
Release date	AT fish	PIT-tagged fish	AT fish	PIT-tagged fish
5 June	1.0 (1)	0.8 (4)	2.8 (2)	2.3 (11)
6 June	0.0 (0)	0.5 (3)	1.0 (1)	1.7 (11)
7 June	0.0 (0)	0.3 (2)	2.7 (2)	1.7 (11)
8 June	0.0 (0)	0.6 (4)	0.0 (0)	1.2 (8)
9 June	1.4 (1)	0.0 (0)	3.2 (2)	1.8 (10)
12 June	6.3 (2)	0.0 (0)	1.4 (1)	2.1 (13)
13 June	0.0 (0)	0.3 (2)	0.0 (0)	1.2 (8)
14 June	0.0 (0)	0.6 (3)	4.4 (1)	0.7 (4)
15 June	0.0 (0)	0.0 (0)	3.3 (2)	0.9 (5)
16 June	0.0 (0)	0.0 (0)	4.2 (1)	1.3 (9)
19 June	0.0 (0)	0.3 (3)	1.9 (1)	0.7 (8)
20 June	0.0 (0)	0.0 (0)	0.0 (0)	3.9 (9)
21 June	0.0 (0)	0.9 (2)	0.0 (0)	0.9 (2)
22 June	0.0 (0)	0.0 (0)	0.0 (0)	1.1 (4)
23 June	0.0 (0)	0.2 (1)	0.0 (0)	2.7 (11)
26 June	0.0 (0)	0.4 (2)	0.0 (0)	0.8 (4)
27 June	0.0 (0)	0.0 (0)	4.4 (1)	1.0 (5)
28 June	0.0 (0)	0.3 (2)	4.1 (1)	0.5 (3)
29 June	0.0 (0)	2.3 (1)	6.6 (1)	4.6 (2)
30 June	0.0 (0)	0.0 (0)	4.5 (1)	1.5 (2)
3 July	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (3)
4 July	0.0 (0)	0.0 (0)	0.0 (0)	4.6 (8)
5 July	0.0 (0)	1.2 (1)	0.0 (0)	5.0 (4)
6 July	0.0 (0)	1.7 (5)	0.0 (0)	3.1 (9)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.4 (40)	0.3 (35)	1.8 (17)	1.6 (165)

Discussion

Detection probabilities are estimates of the proportion of migrating PIT-tagged fish guided into the facility bypass system at a dam and electronically detected. Detection probabilities can vary by location, through time at the same location, and between populations of fish. Successful fish guidance varies according to many factors including the type of equipment and engineering utilized at a particular facility, daily operations (e.g., the amount of spill that is occurring at the time of fish passage), and environmental conditions such as flow and the level of debris in the water column.

Guidance efficiencies can also vary depending on the behavior and physiological condition of migrating fish (Giorgi et al. 1988; Gessel et al. 1991). Once fish have entered the bypass system, detection efficiency can vary depending on the configuration of fish with respect to monitors (proximity and angle), number of monitors at the project, turbulence during fish passage, electromagnetic interference, project hydraulics, antenna shield designs, and fish density (Stein et al. 2004).

In spring 2007, considerable variability in average detection probability was observed between detection sites for yearling Chinook salmon. This variability was likely due in part to a combination of the aforementioned variables and was to be expected. Additionally, we observed differences in detection probabilities between treatment groups for fish that had been commingled upon release. AT fish were more likely to be detected at Little Goose Dam, and PIT-tagged fish were more likely to be detected further downstream at both McNary and Bonneville Dams. Although differences in average detection probability between groups were relatively small, these observations may indicate that some fish from the two groups were either behaving differently as they approached the dam, or that their ability to be detected once present in the bypass system differed depending on treatment.

In addition, the PIT-tag detection probabilities of AT fish were adjusted downward for locations where an AT fish with no PIT detection was later detected on an acoustic node downstream. AT fish were adjusted down (and survival probabilities up) for 5 of 6 detection locations (survival and detection probabilities were not adjusted at Lower Monumental Dam). A similar adjustment for tag loss was not possible for PIT-tag only fish. Therefore, the differences observed at both McNary and Bonneville Dams may have been artifacts of the analyses.

Because similar travel times were observed between the two treatment groups for most release pairs and detection locations, we assumed that commingled treatment groups were arriving at detection locations at roughly the same time, and thus experiencing similar environmental conditions. The only significant difference in travel time between the two treatment groups (0.5 d) was observed at John Day Dam, where we observed no significant difference in detection probability between the two groups.

Subtle differences in behavior between treatment groups could have contributed to the difference in detection probabilities at Little Goose, McNary, and Bonneville Dam. For example, vertical position in the water column might differ among AT and PIT-tagged fish due to variable depth compensation abilities between the two treatments. The ability to compensate at depth might vary due to differential tag burden experienced between the two groups or to a more complex causality such as reduced fitness in one of the groups. Perry et al. (2001) observed that changes in depth/pressure affected buoyancy to a greater extent in fish implanted with dummy radio transmitters (minus a trailing antenna), compared to control fish. Based on these observations, they cautioned that tagged fish may expend more energy swimming in order to maintain buoyancy at depth compared to non-tagged fish, or tagged fish might travel at shallower depths in order to compensate for the higher costs of maintaining neutral buoyancy.

In calculating detection probabilities for AT fish, the use of AT detections on acoustic nodes downstream was intended to correct for PIT-tag loss, in addition to increasing the precision of survival estimates for AT treatment fish (Appendix C). As a result of adjustments based on these acoustic detections, the detection probabilities for AT fish were adjusted down (and survival probabilities up) for 5 of 6 detection locations (survival and detection probabilities were not adjusted at Lower Monumental Dam). If true PIT-tag loss was > 0%, but was similar between the two treatments or higher in PIT-tagged fish, these corrections would have produced biased estimates. However, there is little reason to suspect that this was the case: in the extended holding study (reported here), observed PIT-tag loss was slightly higher in AT (2%) than in PIT-tagged fish (0.3%), though the difference was not significant ($P = 0.64$).

Comparisons of the non-adjusted data showed average detection probabilities 5 to 7% higher for AT fish at Little Goose ($P = 0.002$), John Day ($P = 0.135$), and Bonneville Dam ($P = 0.002$). In contrast, comparisons using the non-adjusted data showed that average detection probabilities varied by no more than 1% between treatments at Ice Harbor, Lower Monumental, and McNary Dam. A detailed discussion of the methods used to calculate detection and survival estimates for AT fish is presented by Skalski and Buchanan in Appendix C of this report.

Similar to the radio-tagging results reported by Hockersmith et al. (1999, 2003), statistically significant differences in survival between tag treatments (PIT>AT) for yearling Chinook were apparent during this study. Also similar to the radio-tagging studies, these differences appeared to develop over time and distance from release. Average tag burdens by weight experienced by radio- and acoustic-tagged fish were similar among our study and both studies of Hockersmith et al.

Our results differed from those of the JSATS pilot, a precursor to this study conducted in 2006 (Hockersmith 2007). In the pilot study, survival estimates were similar between acoustic- and PIT-tag treatments at all but one detection site, where survival was higher for acoustic-tagged fish. However, as discussed previously and emphasized by Hockersmith et al. (2007), the initial JSATS acoustic-tag study suffered from low sample sizes and far fewer replicates than were originally intended. Larger and more representative samples of fish tagged in 2007 imparted more power to this study for identifying differences between treatments. Furthermore, an additional increase in numbers of AT releases appears to be warranted to provide even greater test sensitivity in future studies.

Potential relationships between relative tag effects and size (length) of fish at the time of tagging are being explored in ongoing analyses. Preliminary results suggest that relative survival (AT/PIT) was likely lower for smaller fish in 2007 (S. Smith, NMFS, personal communication). Length and or weight relationships between survival and tag burden have been explored during previous laboratory studies (Brown et al. 2007b; Lacroix et al. 2004; Moore et al. 1990), albeit with variable results.

Covariate analyses are ongoing to investigate potential relationships of environmental and biological factors with survival estimates (i.e., tag effects). Data suggest a trend in survival over time that may be related to environmental parameters such as flow or time of release. At McNary Dam, for example, mean relative survival AT/PIT for inriver migrating fish was 0.89 for fish released through 5 May and 1.00 for fish released during 9-15 May. Differential survival (PIT>AT) downstream at Bonneville Dam was apparent for all groups but the 15 May release group.

Initial covariate analyses (see Appendix F) indicated that relative survival to McNary Dam was associated with with tag burden, fork length, condition factor, water temperature, and river discharge. Survival of AT fish relative to PIT-tagged fish decreased with increasing tag burden, increased with increasing fork length, increased with increasing condition factor, increased with increasing water temperature, and increased with increasing river discharge. However, the multivariable analyses demonstrated strong multicollinearity among predictor variables, making interpretation of the regression analysis difficult.

More sophisticated statistical techniques may be capable of clarifying these relationships. For a tag-recapture data set of this size and complexity, estimation of models, including a mixture of tag-group level (e.g. flow exposure) and individual-level (e.g. length at tagging) covariables is extremely computation-intensive, apparently near the limits of state-of-the-art software like SURPH and MARK. Fitting of a single model can take hours even on powerful computers. Analyses of 2007 data were delayed in part because of this difficulty. When 2008 data became available before analyses of 2007 data were complete, we determined that these important analyses would benefit greatly from an additional year of data. Analyses of 2007-2008 data will be reported when complete (S. Smith, NMFS, personal communication).

Although results from analyses of detection probability and survival indicated that AT fish were not likely behaving in the same manner or surviving at the same rates as PIT fish, results from the comparative avian predation analyses suggested that AT fish were no more vulnerable to avian predators than the PIT fish as they migrated through the upper river and estuary.

Similar to findings for the yearling fish, successful PIT-tag detection of subyearling Chinook was dependent on two factors: guidance into the bypass system and subsequent electronic detection. These factors in turn were dependant on several environmental and biological variables, which would be expected to vary between detection sites as well as to vary temporally at the same site.

Unlike the comparisons observed for yearling Chinook, average travel times for subyearling Chinook differed significantly at most downstream detection sites. The AT fish groups needed significantly more time than PIT-tagged groups to reach all detection sites on the Snake River. This discrepancy in rate of travel suggests that AT and PIT fish may have been exposed to different environmental conditions as they approached each project bypass system. This dissimilarity alone could explain the difference in detection probability observed between AT and PIT fish at Little Goose Dam. Alternative explanations would potentially include behavioral differences between the two treatment groups and differential tag loss (PIT>AT) between groups. We attribute the low detection numbers of AT fish below McNary Dam and of AT pilot fish at all locations to mortality.

Although behavior was not directly examined, significant differences in travel time to Little Goose, Lower Monumental, Ice Harbor, and McNary Dam suggested that AT and PIT fish were not migrating downstream in exactly the same manner. Possible behavioral difference was also indicated by different rates of survival to Little Goose and McNary Dam. Lower survival of AT fish to Little Goose Dam may indicate that at least a component of the AT fish approaching this detection site was less fit than their PIT-tagged counterparts. A fish that was moribund would likely be slower or less direct in its swimming and may have difficulty maintaining neutral buoyancy at depth compared to a healthy fish.

Similar to the yearling groups, we also observed differential tag loss between treatment groups in subyearling fish held in the laboratory for 90 d (AT>PIT), although the direction of this difference was not consistent with the higher detection probability observed at Little Goose for AT fish. Also similar to yearling fish, detection probability estimates were adjusted down at both Little Goose and McNary Dams for AT fish when downstream AT detections were considered. If PIT-tag loss in the field was >0% but similar between the two treatments, or higher in the PIT tagged fish, then these adjustments may have obscured even larger differences in detection probability between the two groups.

Differences in relative survival (PIT>AT) were more pronounced and manifest closer to the point of release for subyearling than for yearling Chinook treatment groups. There also appeared to be a trend in relative survival of subyearling Chinook over time, with larger differences between treatments observed later in the migration. Average relative survival (AT/PIT) to McNary Dam was 0.42 for subyearling groups released before 25 June and 0.33 for those released after.

While river flow in the Snake and Columbia Rivers tends to increase over time during spring, the opposite occurs during summer. As flow decreases, water temperature typically increases. Not surprisingly, both of these environmental trends were observed during the 2007 subyearling migration season. Flow measured at Lower Granite Dam exhibited a fairly steady decline from 4 June to 13 July (56.25 to 33.12 kcfs), while water temperature remained fairly constant until 25 June, fluctuating from 15.6 to 17.2°C. Temperature increased to 19.4°C on 26 June and eventually peaked and remained elevated above 20°C from 6 to 10 July. Timing of riverine temperature spikes coincided with the increase in differential survival observed in the subyearling release.

The idea that relatively high tagging temperatures will adversely affect survival and tag retention in surgically tagged fish is not novel, and the effects of temperature have been reported by others (Bunnell and Isely 1999; Knights and Lasee 1996; and Walsh et al. 2000). Chinook salmon are poikilotherms, and as such their metabolism increases as the environment warms. As metabolic rates go up, oxygen consumption rates increase, and stressors such as handling, holding, and anesthesia are more likely to compromise these fish (Noga 1996). This is of particular concern when tagging is conducted at a time when the river itself is becoming more active biologically (e.g.

bacteria and parasites are reproducing quickly), and piscivorous predators such as Northern pikeminnow, bass, and catfish are also becoming more active (Vig and Burley 1991; Tabor 1993).

Smith et al. (2003) reported similarly strong correlations between survival and water temperature, river discharge, and water transparency in relation to a PIT-tagging study. Unfortunately, due to the fact that all three of these variables were highly correlated with each other, they were unable to determine which most influenced survival. Our initial covariate analyses (Appendix F) performed on the 2007 data were similarly inconclusive, mostly due to collinearity among explanatory factors such as release date, river discharge, water temperature, and average size of fish released.

Potential relationships between relative tag effects and size (length) of fish at the time of tagging are also being explored. Certainly, a rudimentary comparison between the number of downstream detections of PIT-tagged, AT pilot, and AT fish suggests that size at tagging played a role in survival on some level. Preliminary results also suggest that relative survival (AT/PIT) is likely lower for smaller fish within the AT group. As described above, techniques to clarify all of these relationships are being applied to data from both 2007 and 2008, and will be reported when complete (S. Smith, NMFS, personal communication).

Similar to the yearling Chinook salmon groups, results from the comparative avian predation analysis suggested that subyearling AT fish were no more vulnerable to avian predation than PIT-tagged fish as they migrated through the upper river and into the estuary.

GROSS NECROPSY AND HISTOLOGICAL EVALUATIONS OF MIGRATING JUVENILE SALMON

Executive Summary

Yearling Chinook Salmon. Up to 10 yearling Chinook salmon from each tag treatments (AT and PIT-tagged) and from each of the 10 commingled release groups were recaptured during migration using the separation-by-code (SbyC) systems at McNary and Bonneville Dam. After recapture, fish were euthanized and examined for tag loss, disease, and histological change due to tag implantation. At the time of necropsy, kidney tissue samples were also collected and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). A group of 30 non-tagged reference fish was used to provide baseline data for comparisons of gross necropsy, histological evaluation, and assessments of BKD antigen in AT and PIT-tag treatment fish. Reference fish were taken from hatchery yearling Chinook collected at Lower Granite Dam for evaluations of migration behavior and survival.

Gross necropsy revealed less ceacal fat in fish from both tag treatments than in reference fish, with PIT-tagged fish tending to have more ceacal fat than AT fish. The same trends were observed for mesenteric fat content. In general, splenic engorgement/enlargement was more prevalent in treatment fish of both tag types than in reference fish. The percentage of fish observed with food in the stomach increased for all groups as fish migrated downstream. However, PIT-tagged fish had a higher percentage of individuals with food in the stomach than AT fish in subsamples from both dams. Liver abnormalities were more prevalent in fish recaptured at both downstream dams than in fish from Lower Granite Dam, and more prevalent in AT than in reference or PIT-tagged fish. Kidney abnormalities were more prevalent in fish recaptured at the dams than in reference fish, but were equally prevalent between the two tag treatments. We did not evaluate gross necropsy results statistically.

Comparative histopathology analysis showed significant differences between tag treatments (AT and PIT) in 6 of 42 parameters/conditions evaluated for yearling Chinook recaptured at both dams combined. Indicators of nutritional condition found to be significantly different between treatments were not consistent in direction, and therefore did not support a trend for either treatment group relative to the other. On the other hand, significant differences between groups (AT>PIT) were found with respect to the presence of chronic peritonitis internally at the site of the incision. Furthermore, several metrics used to evaluate incision/injection site closure indicated that AT fish had significantly more evidence of inflammation in the peritoneal cavity than PIT fish and that overall closure/healing at the injection site had progressed further in PIT-tagged fish.

Comparative histopathology between tag treatments in fish recaptured at McNary vs. Bonneville Dam showed many of the same general trends as the combined analysis. The one exception was that in fish recaptured at McNary Dam, a higher percentage of AT than PIT-tagged fish showed splenic congestion. Analysis by length class for fish sampled at both sites revealed a clear pattern in the amount of mesenteric fat present, with larger fish having more. There was also a general pattern in incision apposition by size class, with better and more complete apposition observed in progressively larger fish. A clear and significant progression in re-knitting of the dermal stratum compactum was also seen in PIT-tagged fish according to fish length, with larger fish showing a greater tendency toward incision healing.

Rs antigen levels were evaluated using enzyme-linked immunosorbent assay (ELISA). For hatchery yearling Chinook, Rs antigen levels ranged from 0.070 to 0.131 in reference fish, 0.07 to 0.133 for fish of both tag treatments recaptured at McNary Dam, and 0.068 to 0.298 for fish of both tag treatments recaptured at Bonneville Dam (with two others at 0.463 and 1.613). Since Rs antigen levels were low for all but a few fish, no further analyses were conducted to evaluate differences among collection sites or tag treatments.

Subyearling Chinook Salmon. For subyearling Chinook salmon, up to 10 fish from each release and treatment combination were targeted for recapture using the SbyC system at Bonneville Dam. At McNary Dam, the SbyC system was not operating during the study period, and no subyearling study fish were recaptured from this location. After recapture, fish were euthanized and examined for tag loss, disease, and histological changes due to tag implantation. A group of 79 non-tagged reference fish were necropsied in the same manner as tagged fish to provide baseline data for comparison. Reference fish were taken from collections at Lower Granite Dam of wild and hatchery subyearling Chinook for evaluations of migration behavior and survival.

Gross necropsy of reference fish collected at Lower Granite Dam and of treatment fish recaptured at Bonneville Dam revealed some important trends among study groups. In general, less caecal fat was observed in fish belonging to both tag treatment groups collected at Bonneville Dam compared to reference fish, though PIT-tagged fish tended to have more caecal fat than AT fish. Similar trends were observed with respect to mesenteric fat content. Liver and kidney discoloration and or abnormalities were more prevalent in fish recaptured at Bonneville Dam than in reference fish, and more prevalent in AT than PIT-tagged fish. Similar to the yearling group, we did not evaluate the gross necropsy results statistically.

Results from comparative histopathology analyses between tag treatments showed significant differences in 6 of 43 parameters/conditions evaluated in subyearling Chinook recaptured at Bonneville Dam. Overall indicators of nutritional condition, such as the presence of mucosal glycogen stores in the intestine and digestive enzymes in the exocrine pancreas, were significantly higher for PIT than AT fish. A significantly larger percentage of AT than PIT fish were observed to have chronic peritonitis within the peritoneal cavity at the site of the incision. Evidence of healing at the incision/injection site was significantly greater in the PIT fish.

For recaptured fish from both tag treatments, analysis by length class revealed a clear pattern across length classes for the presence/absence of liver lymphocytic infiltrates, with inflammatory cells observed more often in smaller fish. Mesenteric adipose was significantly higher in 12-13 cm fish than 11-12 cm fish. A significantly higher percentage of AT than PIT fish had chronic peritonitis within the peritoneal cavity at the site of surgical incision. Mesenteric adipose tissue was significantly higher in 12-13 cm fish than in 11-12 cm fish.

Rs antigen levels, as measured by ELISA, ranged from 0.070 to 0.213 in reference fish and from 0.078 to 0.442 in fish of both tag types recaptured at Bonneville Dam. Of 70 samples, Rs antigen levels exceeded 0.299 in only 2. Because values for all but a few fish were considered low, no statistical analyses were conducted to evaluate differences between sites or among treatment groups.

Introduction

In addition to comparing migration behavior and survival of AT and PIT-tagged Chinook salmon, we recaptured and examined fish from each tag treatment at two locations along the migration route. Numerous laboratory studies have examined the physiological effects of surgical tagging (Brown et al. 2007a; Knights and Lasee 1996; Liedtke et al. 2007; Marty and Summerfelt 1986, 1990; Walsh et al. 2000). However, it is imperative to examine tagged fish after release to the field, where impacts of a given tagging procedure and/or tag can be manifested outside of the more forgiving laboratory environment. Through this diagnostic work, we also hoped to gain insight into the potential mechanism(s) responsible for any tag effects observed.

After study fish were recaptured using the sort by code (SbyC) systems at McNary and Bonneville Dam, they were euthanized, measured, weighed, and evaluated for wound healing and external abnormalities such as descaling and hemorrhaging. Necropsies were also performed on each SbyC fish, with a gross examination of internal organs and tissues for possible reactions to tagging, such as tag encapsulation. Tissue samples were collected for histological exam as well as to determine individual levels of antigen for *Renibacterium salmoninarum* (Rs), the bacterial agent responsible for bacterial kidney disease (BKD). Gross necropsy and histology results were compared among treatments to evaluate potential health-related effects of tagging, such as differences in nutritional condition, wound closure, and the presence of peritonitis. Levels of Rs antigen were compared among treatment groups to evaluate whether or not acoustic-tagged fish were more susceptible to BKD than PIT-tagged fish. Necropsy data collected at the time of tagging were used to establish reference fish condition and to rule out pre-existing infectious or idiopathic disease that might have affected fish performance or survival.

Methods

Fish Collection

During spring and summer 2007, fish were collected at Lower Granite Dam for comparisons of behavior and survival between AT and PIT-tagged fish (first section of this report). From these collections, we set aside 30 non-tagged hatchery yearling Chinook salmon in spring and 79 non-tagged subyearling Chinook (wild and hatchery) in summer. These groups were used as reference fish to provide baseline data for evaluations of tag effects from gross necropsy, and assessment of BKD prevalence. Reference fish were not included in histological evaluations.

Treatment fish for gross necropsy, histological examination, and assessment of BKD were subsamples of AT and PIT-tagged yearling and subyearling Chinook replicates tagged and released at Lower Granite Dam for migration behavior and survival studies. Actively migrating AT and PIT-tagged fish were recaptured using the SbyC systems at McNary and Bonneville Dam; these systems allow PIT-tagged fish to be selectively recaptured based on their PIT-tag code (PSMFC 2008). Yearling and subyearling release groups were collected, examined, and analyzed separately.

Yearling Chinook treatment fish were divided into 20 unique groups based on release date (groups were released on 10 dates) and treatment (AT or PIT). The SbyC systems at both downstream dams were programmed to collect the first 10 fish detected from each group, for a maximum of 200 recaptures at each downstream dam (10 fish/group × 2 tag treatments × 10 release groups).

For subyearling Chinook, we followed a similar protocol after first pooling consecutive release groups to reduce the number of groups from 27 to 13. Reducing the number of recapture groups facilitated coordination of separation-by-code actions among personnel from various agencies at the dams. Fewer target groups also helped to ensure adequate sample sizes for each recapture group. In total, 39 unique groups of subyearling Chinook were targeted for SbyC diversion, for a maximum of 390 recaptures at Bonneville Dam (10 fish/group × 3 treatment groups × 13 release groups). The SbyC system was not operational at McNary Dam during the subyearling study period, so recaptures could not be taken from this location.

Targeting the first 10 fish from each release/treatment may have biased recapture samples in favor of the 10 healthiest or strongest fish from each group. However, this protocol also provided for minimal collection impacts on study fish and bycatch, as well as consistent, systematic programming instructions for the SbyC systems.

At McNary Dam, we successfully recaptured a total of 169 hatchery yearling Chinook (75 AT and 89 PIT fish). At Bonneville Dam, we recaptured 144 hatchery yearling Chinook (64 AT and 79 PIT) and 80 subyearling Chinook (9 AT and 71 PIT). Treatment fish were sacrificed immediately after recapture, and reference fish were sacrificed immediately after collection.

Variability in sample size between tag treatments may have resulted from unequal release numbers between treatment groups, differential survival, dissimilar routes of passage, or a combination of these variables.

Necropsy and Tissue Collection

Upon recapture in the SbyC system, study fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004). Each fish was measured, weighed, and evaluated for external abnormalities and gross visible injury, such as lesions, descaling, or hemorrhaging. Necropsies were performed on each fish in the manner of Noga (1996). Fish were examined for gross tissue response to tagging, such as tag encapsulation. The following metrics were evaluated using a Goede index scoring system (Goede and Barton 1990): smolt index, eyes, fins, gills, pseudobranchs, caecal fat, mesenteric fat, spleen, food in stomach, hind gut, liver, gall bladder, sex, and kidney. A description of the numeric scale used to evaluate the metrics accompanies the results (Tables 16 and 19).

Although we consistently utilized the same trained personnel to perform gross necropsies at each location (Lower Granite, McNary, and Bonneville Dams), personnel were inconsistent between locations. Due to the subjective nature of the rating system, statistical analysis of gross necropsy results was not conducted. Results among treatments were instead compared to reveal general trends and to validate statistical analyses of the histological examination results.

Along with gross necropsy records, tissue samples for histological examination were taken from the gill, heart, liver, head kidney, trunk kidney, spleen, upper intestine, lower intestine, skin in area of the incision/suture, and pyloric ceca. Tissues for histology were placed into one of three separate cassettes labeled gill (gill), soft tissue (heart, liver, head and trunk kidney, spleen, upper and lower intestine and pyloric ceca), and incision (skin in area of incision/suture). All tissue samples were place directly into Davidson's solution for fixation and left undisturbed for 7-14 d.

After fixation, tissue samples were rinsed with distilled water and transferred to 70% ethyl alcohol for continued preservation until they were processed further. Fixed tissues were dehydrated, processed using a Shandon Hypercenter XP automated tissue processor, and embedded in Polyfin (Triangle Biomedical Sciences). Tissues sections (4-5µm thick) were stained with haematoxylin and eosin-phloxine (Luna 1968) and examined by light microscopy at the Ecotoxicology and Environmental Fish Health Program laboratory of the Northwest Fisheries Science Center in Seattle, WA (see Appendix E for a table showing specific indices evaluated under microscopy, as well as the scale used for scoring each index).

Histological Analyses

Fish used for histological analyses were the same migrating tag treatment fish recaptured in the SyC systems at Bonneville and McNary Dam for yearling Chinook and in the SbyC at Bonneville for subyearling Chinook. Reference fish were the same fish taken at the time of tagging at Lower Granite Dam (anesthetized but not tagged).

Tissue samples were evaluated using 42 histological metrics for yearling and 43 metrics for subyearling fish: four metrics were scored on an ordinal scale of 0 to 3, four on an ordinal scale of 0 to 7, and the remainder scored by presence/absence (Appendix E). After all tissue samples were evaluated, scores were coded into a StatView Spreadsheet (Abacus Concepts), and data were compared by treatment group, size class, and collection location using chi-square contingency tables, Fisher's exact test (presence/absence data), or ANOVA followed by Fisher's protected least significant difference test (ordinal data).

Tag treatment fish were also compared by size class. For these analysis, yearling Chinook sizess were rounded to the nearest 1 cm and binned into groups of 11-12, 13, 14, and 15-16 cm. Subyearling fish were binned into similar groups to increase sample sizes and create comparable samples between tag treatments.

	Yearling Chinook size class (cm)			
	11-12	13	14	15-16
AT (N)	37	58	34	7
PIT (N)	43	53	43	18
Total	80	111	77	25
	Subyearling Chinook size class (cm)			
	9-10	11	12-13	
AT (N)	6	1	2	
PIT (N)	23	27	9	
Total	29	28	11	

Prevalence of *Renibacterium salmoninarum*

Kidney tissue samples were also collected from each sampled and recaptured fish at the time of necropsy and examined for the antigen to *Renibacterium salmoninaru*m (Rs), the causative agent of bacterial kidney disease (BKD). Fresh kidney samples were excised and placed into individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). Samples were frozen and transported on ice to the Northwest Fisheries Science Center. In the laboratory, kidney samples were thawed, diluted 1:4 (w/v) in 0.01-M phosphate-buffered saline with 0.05% Tween 20, homogenized using a print roller and then frozen in screw cap tubes.

For each treatment and release group combination, the Rs antigen was determined based on enzyme-linked immunosorbent assay (ELISA) as described by Pascho and Mulcahy (1987) and modified by Pascho et al. (1991). Coating and conjugate antibodies (Kirkegaard and Perry Laboratories, Gaithersburg MD) were used at dilutions of 1:1500 and 1:4000 respectively. Optical densities were read at 405 nm using an automated 96-well plate reader (Model ELx808 IU, Bio-Tek Instruments, Winooski, VT). Negative controls and blanks, as well as substrate and conjugate controls, were run for each assay. ELISA values were reported as absolute readings, without subtracting values for blanks or negative controls.

Values obtained from ELISA testing represented an index of the magnitude of Rs bacteria present, and absolute values were not functionally related (e.g. the difference between 0.08 and 0.09 did not correspond to the difference between 2.5 and 2.7 via a mathematical function). Therefore, to construct metrics for “measuring” levels of BKD, it was prudent to map the values with an indexing system to more robustly represent “distance” between ELISA values. We used the mapping

$$\{(0.000 - 0.199) \rightarrow 1; \quad (0.200 - 0.999) \rightarrow 2; \quad (1.000 - 4.000) \rightarrow 3\}$$

when values across this range occurred. These values, which were used to group results as either low, medium, or high, reflect levels used in previous studies for broodstock segregation. Pascho et al. (1991) categorized infection levels based on the detection of Rs antigen using values of <0.199 as reflecting a low level of infection, 0.2 to 0.999 as a medium level, and values equal to or greater than 1.0 as indicating a high level of infection. For each release group (date) by treatment, the average across samples was calculated for this metric. Kruskal-Wallis non-parametric tests were used for all treatment comparisons (Hollander and Wolfe 1973).

Results

Yearling Chinook Salmon

Gross Necropsy--Results from necropsy of yearling Chinook salmon sampled at Lower Granite Dam (reference fish), or recaptured at McNary and Bonneville Dam (AT and PIT fish) are displayed in Table 16.

On gross exam, yearling Chinook appeared to be within normal limits across all sampling sites and for both treatments (AT and PIT fish) for eyes, gills, pseudobranchs, and hind gut. Overall, fish recaptured at McNary Dam (AT and PIT fish) were described as being more heavily smolted than fish sampled at Lower Granite Dam. Fish recaptured at Bonneville Dam were also described as being more heavily smolted than fish sampled at Lower Granite Dam. However, these same fish were described as being less smolted than fish recaptured at McNary Dam. A larger percentage of fish recaptured at McNary Dam were described as having frayed fins than those sampled at Lower Granite Dam. Fish recaptured at Bonneville Dam were described as having the largest percentage of normal fins compared to those sampled at Lower Granite and recaptured at McNary Dam. Percentages of normal and frayed fins were similar between the two treatments (AT & PIT fish) recaptured at each location.

The percentage of caecal fat reported in study fish decreased from Lower Granite Dam to McNary Dam: Bonneville Dam fish had a slightly higher percentage of fish in the "little" vs. "none" category compared to McNary Dam. However, fish recaptured at Bonneville were still reported to have less caecal fat than fish sampled at Lower Granite. In general, there was less caecal fat reported for AT than PIT fish at both McNary and Bonneville Dams.

Recaptured fish from McNary Dam trended towards having less mesenteric fat compared to reference fish examined at Lower Granite Dam. Mesenteric fat percentages were similar between fish from McNary and Bonneville Dams. PIT fish had slightly higher mesenteric fat content at both sites compared to AT fish. All fish sampled at Lower Granite Dam were reported having a normal looking spleen on gross exam. In contrast, 9% of the AT and 8% of the PIT fish recaptured at McNary were described as having enlarged spleens, and 5% of AT and 1% of PIT fish recaptured at Bonneville were described as having enlarged spleens.

Table 16. Gross necropsy results for yearling Chinook salmon sampled at Lower Granite Dam (reference) and recaptured at McNary and Bonneville Dam (acoustic and PIT tag treatments). Samples were scored following a Goede index and were evaluated for the metrics listed. Columns show the proportion of treatment fish corresponding to each metric score by location. Standard errors are in parentheses.

	Yearling Chinook Salmon sampled (%)				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
Metric	Reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Smolt_Index					
0-Fully smolted	0.50 (0.09)	0.97 (0.02)	0.98 (0.02)	0.58 (0.06)	0.70 (0.05)
1-Moderately smolted	0.50 (0.09)	0.01 (0.01)	0.02 (0.02)	0.39 (0.02)	0.28 (0.05)
2-Weakly smolted	0.00	0.01 (0.01)	0.00	0.02 (0.02)	0.03 (0.02)
3-No smoltification observed	0.00	0.00	0.00	0.02 (0.02)	0.00
Eyes					
0-Normal	1.0 (0.00)	0.95 (0.03)	0.98 (0.02)	0.98 (0.02)	1.0 (0.00)
1-Diminutive	0.00	0.00	0.00	0.00	0.00
1-Hemorrhagic	0.00	0.05 (0.03)	0.01 (0.01)	0.00	0.00
1-Exopthalmic	0.00	0.00	0.01 (0.01)	0.02 (0.02)	0.00
1-Cataract	0.00	0.00	0.00	0.00	0.00
1Blind or Missing	0.00	0.00	0.00	0.00	0.00
Fins					
0-Normal	0.90 (0.05)	0.68 (0.05)	0.73 (0.05)	0.94 (0.03)	0.95 (0.02)
1-Opaque	0.00	0.03 (0.02)	0.02 (0.02)	0.02 (0.02)	0.00
2-Frayed	0.10 (0.05)	0.30 (0.05)	0.24 (0.05)	0.05 (0.03)	0.05 (0.02)
3-Clubbed or Missing	0.00	0.00	0.00	0.00	0.00
Gills					
0-Normal	1.0 (0.00)	1.0 (0.00)	0.98 (0.02)	1.0 (0.00)	1.0 (0.00)
1-Pale	0.00	0.00	0.02 (0.02)	0.00	0.00
2-Marginate	0.00	0.00	0.00	0.00	0.00
3-Clubbed	0.00	0.00	0.00	0.00	0.00

Table 16. Continued.

	Yearling Chinook Salmon sampled (%)				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
	Reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Pseudobranchs					
0-Normal	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)
1-Swollen	0.00	0.00	0.00	0.00	0.00
2-Lithic	0.00	0.00	0.00	0.00	0.00
3-Swollen and Lithic	0.00	0.00	0.00	0.00	0.00
4-Inflammed	0.00	0.00	0.00	0.00	0.00
Caecal Fat					
0-None	0.43 (0.09)	0.95 (0.03)	0.90 (0.03)	0.81 (0.05)	0.74 (0.05)
1-Little, < 50% of caecum covered	0.37 (0.09)	0.05 (0.03)	0.09 (0.03)	0.14 (0.04)	0.15 (0.04)
2-Normal, 50% of caecum covered	0.20 (0.07)	0.00	0.02 (0.02)	0.05 (0.03)	0.11 (0.04)
3-More than 50% of each caecum covered	0.00	0.00	0.00	0.00	0.00
4-Excessive, pyloric caeca completely covered	0.00	0.00	0.00	0.00	0.00
Mesenteric Fat					
0-No body fat present	0.50 (0.09)	0.79 (0.05)	0.73 (0.05)	0.80 (0.05)	0.76 (0.05)
1-Fat body < diameter of caecum	0.40 (0.09)	0.21 (0.05)	0.26 (0.05	0.20 (0.05)	0.24 (0.05)
2-Fat body = diameter of caecum	0.10 (0.05)	0.00	0.01 (0.01)	0.00	0.00
3-Fat body larger diameter than caecum	0.00	0.00	0.00	0.00	0.00
4-Exceed fat, entire body cavity full of fat	0.00	0.00	0.00	0.00	0.00
Spleen					
0-Red	1.0 (0.00)	0.88 (0.04)	0.90 (0.03)	0.49 (0.06)	0.38 (0.05)
1-Black	0.00	0.02 (0.02)	0.01 (0.01)	0.35 (0.06)	0.57 (0.06)
2-Enlarged	0.00	0.09 (0.03)	0.08 (0.03)	0.05 (0.03)	0.01 (0.01)
3-Granular	0.00	0.00	0.01 (0.01)	0.00	0.00
4-Nodular	0.00	0.00	0.00	0.00	0.00
1,2-Black & Enlarged	0.00	0.00	0.00	0.11 (0.04)	0.04 (0.02)

Table 16. Continued.

	Yearling Chinook Salmon sampled (%)				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
	Reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Food in Stomach					
Absent	0.87 (0.06)	0.91 (0.03)	0.87 (0.04)	0.56 (0.06)	0.45 (0.06)
Present	0.13 (0.06)	0.09 (0.03)	0.13 (0.04)	0.44 (0.06)	0.55 (0.06)
Hind Gut					
0-No inflammation	1.00 (0.00)	0.97 (0.02)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)
1-Mild inflammation	0.00	0.01 (0.01)	0.00	0.00	0.00
2-Severe inflammation	0.00	0.01 (0.01)	0.00	0.00	0.00
Liver					
0-Normal; firm reddish brown color	0.93 (0.05)	0.76 (0.05)	0.83 (0.04)	0.63 (0.06)	0.77 (0.05)
1-Slight general discoloration	0.00	0.05 (0.03)	0.00	0.17 (0.05)	0.06 (0.03)
2-Pale	0.07 (0.05)	0.08 (0.03)	0.08 (0.03)	0.20 (0.05)	0.16 (0.04)
3-Fatty liver: coffee-cream color, greasy to touch	0.00	0.08 (0.03)	0.09 (0.03)	0.00	0.00
4-Nodules in liver	0.00	0.00	0.00	0.00	0.00
5-Focal discoloration	0.00	0.04 (0.02)	0.00	0.00	0.00
Gall Bladder					
0-Yellow or straw color; empty or partly full	0.25 (0.08)	0.08 (0.03)	0.20 (0.04)	0.19 (0.05)	0.23 (0.05)
1-Yellow or straw color; full, distended	0.00	0.07 (0.03)	0.07 (0.03)	0.20 (0.05)	0.18 (0.04)
2-light green to "grass" green	0.50 (0.09)	0.57 (0.06)	0.41 (0.05)	0.41 (0.06)	0.53 (0.06)
3-Dark green to dark blue-green	0.25 (0.08)	0.29 (0.05)	0.32 (0.05)	0.20 (0.05)	0.06 (0.03)
Kidney					
0-Normal	1.0 (0.00)	0.97 (0.02)	0.97 (0.02)	0.88 (0.04)	0.87 (0.04)
1-Pale	0.00	0.00	0.02 (0.02)	0.09 (0.04)	0.05 (0.03)
2-Swollen	0.00	0.00	0.00	0.00	0.04 (0.02)
3-Mottled	0.00	0.03 (0.02)	0.01 (0.01)	0.02 (0.02)	0.00
4-Granular	0.00	0.00	0.00	0.02 (0.02)	0.04 (0.02)

In recaptures from McNary Dam, 9% of AT and 13% of PIT fish were observed with food in their stomachs. In recaptures from Bonneville Dam, 44% of AT and 55% of PIT fish had food in their stomachs. Gross exam revealed a trend towards higher percentages of liver discoloration in fish sampled from further downstream sites (Bonneville Dam > McNary Dam > Lower Granite Dam). A larger percentage of AT than PIT-tagged fish were observed to have liver abnormalities. All fish sampled at Lower Granite Dam had normal appearing kidneys on gross exam. In contrast, 3% of both AT and PIT fish recaptured at McNary Dam had pale or mottled kidneys. In recaptures from Bonneville Dam, 13% of study fish from both tag treatments were described as having pale, mottled, or granular kidneys.

Histopathologic Evaluation—Table 17 shows results from the comparative histopathology analysis for yearling Chinook salmon by tag treatment (AT and PIT) and by length class for fish recaptured at Bonneville and McNary Dams combined. Reference fish were generally healthy, indicating no systematic bias to between-treatment comparisons. Table 18 shows comparative histopathology analysis by recapture site tag and tag treatment and by recapture site for both tag treatments combined.

Results from comparative histopathology analysis for fish recaptured at both dams combined showed no significant difference between tag treatments in 36 of the 42 parameters/conditions evaluated. Exceptions fell into three general categories, including nutritional condition, peritoneal inflammation, and incision (AT) or injection site (PIT) healing (Table 18).

Lower intestinal glycogen stores were significantly greater in PIT-tagged than AT yearling Chinook. Lower intestinal glycogen is an indicator of nutritional status, and this metric was rated on a scale of 0 to 3. There was greater evidence (higher prevalence) of chronic peritonitis and incision adhesions in AT than in PIT-tagged fish. This metric was evaluated internally at the site of the incision, and largely reflects adhesions at this location. Although an infectious cause for the observed inflammation cannot be ruled out, there were no obvious signs of infection, such as large amounts of bacteria, in any yearling Chinook samples evaluated.

A significantly greater percentage of PIT-tagged fish than AT fish had evidence of stratum compactum reknitting (reconnection of the stratum compactum layer of the dermis) at the incision/injection site. Poor incision apposition (uneven closure of the two sides of the incision) was more prevalent in AT than in PIT-tagged fish. Uneven closure of the body wall surfaces to either side of the incision or injection site can increase the likelihood that pathogens will enter the body cavity at the wound or incision site.

Table 17. Results of comparative histopathology analysis for yearling Chinook salmon recaptured at Bonneville and McNary Dam combined. Comparative results are shown by tag treatment (AT vs. PIT) and size class. ND, no significant differences found; shading shows significant differences ($P \leq 0.05$).

Parameter/Condition	AT vs. PIT tag	Size class (11-12, 13, 14, or 15-16 cm)
Liver vacuolation	ND	ND
Liver lymphocytic infiltrates	ND	13, 14, 15-16 > 11-12
Liver hydropic vacuolation	ND	ND
Liver coagulative necrosis	ND	ND
Liver eosinophilic hypertrophy	ND	ND
Liver BKD lesions	ND	ND
Liver Ceratomyxa lesions	ND	ND
Pancreatic zymogen	ND	ND
Pancreatic atrophy	ND	ND
Mesenteric adipose	ND	15-16, 14 > 13 > 11-12[a]
Pancreatic inflammation	ND	ND
Head kidney BKD lesion	ND	ND
Small intestinal mucosal glycogen	ND	13, 14, 15-16 > 11-12
Small intestinal digesta presence	ND	ND
Small intestinal digenetic trematodes	ND	ND
Small intestinal inflammation	ND	ND
Small intestinal Ceratomyxa	ND	ND
Lower intestinal mucosal glycogen	> in PIT	11-12, 13 > 14, 15-16
Lower intestinal digesta presence	ND	ND
Lower intestinal digenetic trematodes	ND	ND
Lower intestinal inflammation	ND	ND
Kidney BKD lesions	ND	ND
Heart epicarditis/myocarditis	ND	ND
Kidney tubule epithelial necrosis	ND	ND
Kidney tubule Myxosporea	ND	ND
Kidney tubule hydropic vacuolation	ND	ND
Spleen congestion	ND	ND
Spleen lymphoid depletion	ND	ND
Spleen macrophage aggregates	ND	ND
Spleen fibrosis	ND	ND
Mesenteric chronic inflammation	ND	ND
Mesenteric chronic inflammation severity	ND	ND
Peritonitis, chronic	> in AT	ND
Incision closure	ND	ND
Skin stratum compactum reknitting	> in PIT	15-16> 14, 13> 11-12[b]
Incision chronic inflammation	ND	ND
Incision chronic inflammation severity	> in AT	ND
Dermal muscular necrosis	ND	ND
Dermal hemorrhage/fibrin	ND	ND
Incision, poor apposition	> in AT	ND
Incision adhesions	> in AT	ND
Internal organ evulsion through incision and presence of Saprolegnia	ND	ND

[a] Clear pattern of increase with increasing size

[b] Size difference seen only in PIT group

Table 18. Results of comparative histopathology analysis for yearling Chinook salmon sampled at Bonneville and McNary Dam. Comparative results are shown by recapture site and tag treatment and by tag recapture site for both treatments combined. ND, no significant difference; shading indicates significant difference ($P \leq 0.05$).

	AT vs. PIT tag		Bonneville
	Bonneville Dam	McNary Dam	vs. McNary Dam
Liver vacuolation	ND	ND	> in Bon
Liver lymphocytic infiltrates	ND	ND	> in Bon AT only
Liver hydropic vacuolation	ND	ND	ND
Liver coagulative necrosis	ND	ND	ND
Liver eosinophilic hypertrophy	ND	ND	ND
Liver BKD lesions	ND	ND	ND
Liver Ceratomyxa lesions	ND	ND	ND
Pancreatic zymogen	ND	ND	ND
Pancreatic atrophy	ND	ND	ND
Mesenteric adipose	> in AT	ND	ND
Pancreatic inflammation	> in PIT	ND	>in Bon PITonly
Small intestinal mucosal glycogen	> in AT	ND	> in Bon
Small intestinal digesta presence	ND	ND	> in McNary
Small intestinal digenetic trematodes	ND	ND	> in Bon PITonly
Small intestinal inflammation	ND	ND	ND
Small intestinal Ceratomyxa	ND	ND	ND
Lower intestinal mucosal glycogen	> in PIT	ND	> in Bon
Lower intestinal digesta presence	ND	> in PIT	> in McNary
Lower intestinal digenetic trematodes	ND	ND	ND
Lower intestinal inflammation	ND	ND	ND
Kidney BKD lesions	ND	ND	ND
Heart epi/myocarditis	ND	ND	ND
Kidney tubule epithelial necrosis	ND	ND	ND
Kidney tubule Myxosporea	ND	ND	ND
Kidney tubule HYDVAC	ND	ND	ND
Spleen congestion	ND	> in AT	> in Bon PITonly
Spleen lymphoid depletion	ND	ND	ND
Spleen macrophage aggregates	ND	ND	ND
Spleen fibrosis	ND	ND	ND
Mesenteric chronic inflammation	ND	ND	ND
Mesenteric chronic inflammation severity	ND	ND	> in Bon
Peritonitis, chronic	> in AT	> in AT	ND
Incision closure	> in PIT	ND	ND
Skin stratum compactum reknit	> in PIT	> in PIT	ND
Incision chronic inflammation	ND	ND	> in Bon PITonly
Incision chronic inflammation severity	> in AT	ND	> in Bon
Dermal muscular necrosis	ND	ND	> in McNary
Dermal hemorrhage/fibrin	ND	ND	ND
Incision, poor apposition	> in AT	> in AT	ND
Incision, adhesions	ND	> in AT	ND
Internal organ evulsion via incision and presence of Saprolegnia	ND	ND	ND

Comparative histopathology between treatments at Bonneville and McNary Dams (Table 18) showed patterns similar to those in the combined analysis, with some additional metrics emerging as significant. Among the metrics that were similar, there was higher prevalence of chronic peritonitis in AT than in PIT-tagged fish at both Bonneville and McNary Dams and in data from both sites combined. Additionally, a higher proportion of PIT fish compared to AT fish were observed to have evidence of stratum compactum reknitting at Bonneville and McNary Dams and in the combined data.

Finally, a higher percentage of AT than PIT-tagged fish were described as having poor incision apposition at Bonneville and McNary Dams and in the combined data. Conditions or other histological parameters that showed significant differences in the combined data and were present at significantly different prevalences or levels between the tagging treatments at only one sampling site were also observed. Lower intestinal mucosal glycogen was significantly higher for PIT-tagged than AT fish only at Bonneville Dam.

Additional significant observations were not noted in the analysis for both dams combined because they occurred in fish from only one recapture site. Among these observations was a greater percentage of AT than PIT-tagged fish from McNary Dam with splenic congestion. Splenic congestion can be an indicator of acute and chronic stress or infection. Splenic congestion was also noted on gross necropsy of these fish.

In recaptures from Bonneville Dam only, AT fish had significantly higher amounts of mesenteric adipose tissue and mucosal glycogen in the small intestine, and PIT fish had a higher occurrence of pancreatic inflammation. There was higher prevalence of lower intestinal digesta in PIT fish from McNary Dam. With respect to conditions and other histological observations relating to the incision site, the prevalence of incision closure was higher in PIT than AT fish, but only at Bonneville Dam. Additionally, at Bonneville Dam, AT fish had a higher severity of chronic inflammation at the incision/injection site compared to PIT fish. At McNary Dam, AT fish had a higher prevalence of adhesions at the site of the incision/injection site than did PIT fish.

A comparison between prevalences/severities of histological conditions and metrics in fish from the two sampling sites within each tagging treatment, also revealed some interesting patterns between fish at the respective dams. Within the nutritional status indices, fish from both treatments recaptured at Bonneville Dam had higher hepatocellular glycogen and lipid stores (vacuolation) and more mucosal glycogen in the small and lower intestine compared recaptures from McNary Dam. However, a larger percentage of fish from McNary Dam were observed to have digesta present in their small and large intestines.

Among the systemic inflammatory lesions, AT fish from Bonneville Dam had a higher prevalence of lymphocytic infiltrates in the liver, and PIT-tagged fish had higher prevalences of pancreatic inflammation. Prevalence of digenetic trematodes in the small intestine was significantly higher in fish from both tag types recaptured at Bonneville compared to McNary Dam. However, whenever trematodes were observed, they appeared to be present at commensal levels. Splenic congestion was also more prevalent in fish from Bonneville vs. McNary Dam, but only in PIT-tagged fish.

Among lesions relating to the incision site or surgery, fish from Bonneville were also described as having a higher severity (in both treatments) and prevalence (PIT only) of chronic inflammation at the incision. In contrast, necrosis of the dermal musculature was higher in fish of both tag treatments recaptured at McNary than in those recaptured at Bonneville Dam.

Analysis by length class for fish from both dams and both treatment groups (Table 17), revealed a clear pattern in the amount of mesenteric adipose present in fish belonging to the 11-12, 13, 14, and 15-16 cm size bins, with larger fish having progressively more mesenteric adipose ($P \leq 0.05$). There was also a clear and significant progression of stratum compactum reknitting in the dermis by length class, with larger fish showing greater tendency towards healing, but only in PIT-tagged fish.

Specifically, significantly higher prevalences of this healing process occurred in the larger length classes as shown by Fisher's exact testing ($P \leq 0.05$) as follows:

15-16 cm (22%) > 14 cm (12%), 13 cm (13%) > 11-12 cm (9%)

Other length class effects, such as the presence of liver lymphocytic infiltrates and the amount of small and lower intestinal mucosal glycogen, revealed significant differences between length classes, but with a less clear progression among size bins.

Prevalence of *Renibacterium salmoninarum*—Estimated Rs antigen levels in hatchery Chinook salmon, as measured by ELISA, ranged from 0.070 to 0.131 for fish sampled at Lower Granite Dam prior to tagging. ELISA values ranged from 0.070 to 0.133 for fish recaptured via SbyC at McNary Dam, and from 0.068 to 0.298 (with 2 others at 0.463 and 1.613) for fish recaptured via SbyC at Bonneville Dam. Since ELISA values for all but a few fish were considered low, no statistical analyses were conducted to evaluate differences between sites or among treatment groups.

Subyearling Chinook Salmon

Gross Necropsy—At Bonneville Dam, 80 subyearling Chinook salmon were recaptured via SbyC and immediately euthanized. Results from gross necropsy of these fish and reference fish sampled at Lower Granite Dam are displayed in Table 19 (no tagged fish were sampled at McNary Dam, as the SbyC system was not operating during this period of the study). Samples were scored numerically following a Goede index (Geode and Barton 1990). A description of the numeric scale used to evaluate the metrics presented is included in Table 19.

On gross exam, the majority of fish showed no departure from normal at both sampling sites and for both treatments (AT and PIT fish) for gills, pseudobranchs, eyes, and hind gut metrics. Overall, subyearing Chinook salmon recaptured at Bonneville Dam (both AT and PIT) were described as being more heavily smolted than reference fish. Percentages of fish described as having normal fins were high ranging from 100% for reference fish sampled at Lower Granite Dam and AT fish recaptured at Bonneville to 88% for PIT-tagged fish recaptured at Bonneville Dam. For PIT-tagged fish recaptured at Bonneville Dam, 12% were described as having opaque or frayed fins.

The percent of caecal fat reported in study fish decreased from Lower Granite Dam to Bonneville Dam, and in general, there was less caecal fat observed in AT than in PIT-tagged fish recaptured at Bonneville. The same trend held for percent mesenteric fat. Of the reference fish sampled at Lower Granite Dam, 3% were described as having enlarged spleens compared to respective proportions of 0 and 1% for AT and PIT-tagged fish recaptured at Bonneville Dam. Of the AT and PIT fish from Bonneville, 57 and 52%, respectively, were described as having food in their stomachs. The percentage of fish with liver discoloration was higher in fish recaptured at Bonneville Dam compared to reference fish. AT fish from Bonneville Dam showed a higher percentage of liver discoloration than PIT-tagged fish. Nearly all non-tagged reference fish (99%) sampled at Lower Granite Dam were reported to have normal looking kidneys on gross exam. Of fish recaptured at Bonneville Dam, 33% of the AT fish and 14% of the PIT fish were reported to have either pale or swollen kidneys.

Table 19. Gross necropsy results for subyearling Chinook salmon sampled at Lower Granite Dam (reference fish) and recaptured at Bonneville Dam (AT and PIT fish). Samples were scored following a Goede index and were evaluated for the metrics listed. Columns show the percentage of treatment fish corresponding to each metric score by location. Standard errors are represented in parentheses.

	Fish affected (%)		
	Lower Granite	Bonneville	
	reference (N = 79)	AT (N = 9)	PIT (N = 71)
Smolt_Index			
0-Fully smolted	0.52 (0.06)	1.00 (0.00)	0.94 (0.03)
1-Moderately smolted	0.44 (0.06)	0.00	0.06 (0.03)
2-Weakly smolted	0.05 (0.02)	0.00	0.00
3-No smoltification observed	0.00	0.00	0.00
Eyes			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Diminutive	0.00	0.00	0.00
1-Hemorrhagic	0.00	0.00	0.00
1-Exopthalmic	0.00	0.00	0.00
1-Cataract	0.00	0.00	0.00
1Blind or Missing	0.00	0.00	0.00
Fins			
0-Normal	1.00 (0.00)	1.00 (0.00)	0.88 (0.04)
1-Opaque	0.00	0.00	0.10 (0.04)
2-Frayed	0.00	0.00	0.02 (0.02)
3-Clubbed or Missing	0.00	0.00	0.00
Gills			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Pale	0.00	0.00	0.00
2-Marginate	0.00	0.00	0.00
3-Clubbed	0.00	0.00	0.00
Pseudobranchs			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Swollen	0.00	0.00	0.00
2-Lithic	0.00	0.00	0.00
3-Swollen and Lithic	0.00	0.00	0.00
4-Inflammed	0.00	0.00	0.00
Caecal Fat			
0-None	0.63 (0.05)	0.89 (0.11)	0.76 (0.05)
1-Little, > 50% of caecum covered	0.28 (0.05)	0.11 (0.10)	0.24 (0.05)
2-Normal, 50% of caecum covered	0.09 (0.03)	0.00	0.00
3-More than 50% of each caecum covered	0.00	0.00	0.00
4-Excessive, pyloric caeca completely covered by large amount of fat	0.00	0.00	0.00

Table 19. Continued.

	Fish affected (%)		
	Lower Granite reference (N = 79)	Bonneville AT (N = 9)	Bonneville PIT (N = 71)
Mesenteric Fat			
0-No body fat present	0.65 (0.05)	0.89 (0.10)	0.82 (0.05)
1-Fat body less than diameter of caecum	0.25 (0.05)	0.11 (0.10)	0.18 (0.05)
2-Fat body equal in diameter of caecum	0.10 (0.03)	0.00	0.00
3-Fat body larger diameter than caecum	0.00	0.00	0.00
4-Exceed fat, entire body cavity full of fat	0.00	0.00	0.00
Spleen			
0-Red	0.97 (0.02)	0.22 (0.14)	0.32 (0.06)
1-Black	0.00	0.78 (0.14)	0.56 (0.06)
2-Enlarged	0.03 (0.02)	0.00	0.01 (0.01)
3-Granular	0.00	0.00	0.00
4-Nodular	0.00	0.00	0.00
1,2-Black & Enlarged	0.00	0.00	0.10 (0.04)
Food in Stomach			
Absent	1.00 (0.00)	0.43 (0.16)	0.48 (0.06)
Present	0.00	0.57 (0.17)	0.52 (0.06)
Hind Gut			
0-No inflammation	1.00 (0.00)	1.00 (0.00)	0.99 (0.01)
1-Mild inflammation	0.00	0.00	0.00
2-Severe inflammation	0.00	0.00	0.01 (0.01)
Liver			
0-Normal; firm reddish brown color	0.90 (0.03)	0.56 (0.17)	0.65 (0.06)
1-Slight general discoloration	0.04 (0.02)	0.33 (0.16)	0.32 (0.06)
2-Pale	0.06 (0.03)	0.11 (0.10)	0.03 (0.02)
3-Fatty liver: coffee-cream color, greasy to touch	0.00	0.00	0.00
4-Nodules in liver	0.00	0.00	0.00
5-Focal discoloration	0.00	0.00	0.00
Gall Bladder			
0-Yellow or straw color; bladder empty or partially full	0.11 (0.04)	0.44 (0.17)	0.42 (0.06)
1-Yellow or straw color; bladder full, distended	0.00	0.22 (0.14)	0.25 (0.05)
2-light green to "grass" green	0.86 (0.04)	0.33 (0.16)	0.30 (0.05)
3-Dark green to dark blue-green	0.03 (0.02)	0.00	0.03 (0.02)
Kidney			
0-Normal	0.99 (0.01)	0.67 (0.16)	0.86 (0.04)
1-Pale	0.01 (0.01)	0.33 (0.16)	0.13 (0.04)
2-Swollen	0.00	0.00	0.01 (0.01)
3-Mottled	0.00	0.00	0.00
4-Granular	0.00	0.00	0.00

Histologic Evaluation—Table 20 shows comparative histopathology analysis by treatment (AT vs. PIT-tag) for subyearling Chinook recaptured at Bonneville Dam, along with analysis by length-class for both tag types combined. Reference fish were generally healthy, indicating no systematic bias to between-treatment comparisons. No AT pilot fish (85-94 mm) were recaptured at the dams, so none were available for histological analysis.

A total of 43 parameters or conditions were evaluated by histological exam for subyearling Chinook salmon (parameters and indices for scoring them are described in Appendix E). Results from comparative histopathologic analysis between tag treatments recaptured at Bonneville Dam (Table 20) showed significant differences for 6 of the 43 parameters/conditions evaluated (and two additional parameters were nearly significant at $P = 0.07$). Similar to the yearling fish, these differences fell into the three general categories: nutritional condition, peritoneal inflammation, and incision (AT fish) or injection site (PIT-tagged fish) healing.

Significantly greater amounts of small-intestinal mucosal glycogen, as well as pancreatic zymogen, were observed in PIT-tagged than in AT subyearling Chinook. Incidence of chronic peritonitis was higher in AT fish, and stratum compactum reknitting was higher in PIT-tagged fish. Finally, both chronic inflammation at the incision and evidence of hemorrhaging at the incision/injection site were higher in AT fish.

Analysis by length class of fish from both tag treatments recaptured at Bonneville Dam revealed a clear pattern across length classes for the presence/absence of liver lymphocytic infiltrates. Smaller fish were observed to have these cells more commonly than larger fish. Mesenteric adipose was significantly higher in 12-13 cm fish than the 11-12 cm fish. Nonsignificant trends by size class included a higher likelihood of observing Myxosporea in the kidney tubules of fish 9-10 cm than 11-13 cm. Fish 11-13 cm also tended to have a higher incidence of chronic inflammation at the incision than those 9-11 cm.

Prevalence of *Renibacterium salmoninarum*--Baseline Rs antigen levels measured by ELISA from subyearling Chinook reference fish sampled at Lower Granite Dam ranged from 0.070 to 0.213. Rs antigen levels were estimated for subyearling Chinook treatment fish of both tag treatments combined (AT and PIT) that were recaptured using the SbyC at Bonneville Dam. For the combined tag treatments, Rs antigen levels ranged from 0.078 to 0.442 overall and exceeded 0.299 in only two of these fish. Since ELISA values for all but a few fish were considered low, no statistical analysis was conducted to evaluate differences between detection sites or among treatment groups.

Table 20. Results of comparative histopathology analysis for subyearling Chinook salmon sampled at Bonneville Dam. Comparative results are shown by tag treatment and length class. Fish were grouped in 9-10, 11, and 12-13 cm bins. ND, no difference; Shaded cells show significant differences (P <0.05).

Parameter/Condition	AT vs. PIT tagged	Length class (9-14 cm)	Comments
Liver vacuolation	ND	ND	
Liver lymphocytic infiltrates	ND	9-10, 11> 12-13	
Liver hydropic vacuolation	ND	ND	no affected fish
Liver coagulative necrosis	ND	ND	no affected fish
Liver eosinophilic hypertrophy	ND	ND	one affected fish
Liver BKD lesions	ND	ND	no affected fish
Liver Ceratomyxa lesions	ND	ND	one affected fish
Pancreatic zymogen	> in PIT	ND	
Pancreatic atrophy	ND	ND	two affected fish
Mesenteric adipose	ND	12-13 > 11	
Pancreatic inflammation	ND	ND	
Pyloric caecae mucosal glycogen	ND	ND	
Small intestinal mucosal glycogen	> in PIT	ND	
Small intestinal digesta presence	ND	ND	
Small intestinal digenetic trematodes	ND	ND	
Small intestinal inflammation	ND	ND	
Small intestinal Ceratomyxa	ND	ND	
Lower intestinal mucosal glycogen	> in PIT (P = 0.07)	ND	
Lower intestinal digesta presence	ND	ND	
Lower intestinal digenetic trematodes	ND	ND	
Lower intestinal inflammation	ND	ND	
Kidney BKD lesions	ND	ND	no affected fish
Heart epicarditis/myocarditis	ND	ND	no affected fish
Kidney tubule epithelial necrosis	ND	ND	no affected fish
Kidney tubule Myxosporea	ND	ND	9-10 > 11, 12-13
Kidney tubule HYDVAC	ND	ND	no affected fish
Head kidney BKD[e] lesions	ND	ND	two affected fish
Spleen congestion	ND	ND	
Spleen lymphoid depletion	ND	ND	no affected fish
Spleen macrophage aggregates	ND	ND	
Spleen fibrosis	ND	ND	no affected fish
Mesenteric chronic inflammation	ND	ND	
Mesenteric chronic inflammation severity	> in AT (P = 0.07)	ND	
Peritonitis, chronic	> in AT	ND	
Incision closure	ND	ND	
Skin stratum compactum reknit	> in PIT	ND	
Incision chronic inflammation	ND	ND	
Incision chronic inflammation severity	> in AT	ND	12-13>11, 9-10
Dermal muscular necrosis	ND	ND	
Dermal hemorrhage/fibrin	> in AT	ND	
Incision, poor apposition	ND	ND	no affected fish
Incision, adhesions	ND	ND	
Internal organ evulsion through incision and presence of Saprolegnia	ND	ND	no affected fish

Discussion

Overall, the yearling Chinook salmon sampled at Lower Granite Dam as reference fish appeared healthy, as few abnormalities were noted on gross necropsy and histological exam. Further, ELISA testing for Rs antigen revealed low levels in all baseline fish. External lesions were also rare in fish recaptured downstream; however, our sampling protocol, which targeted the first 10 fish encountered from each treatment/release group, may have biased the subsamples toward more robust fish compared to the group at large.

Internally, indicators of inflammation and/or infection (discoloration in the liver and kidneys) and stress (splenic enlargement) were grossly visible in yearling Chinook from both treatment groups recaptured downstream. Furthermore, these lesions were more prevalent in fish recaptured at Bonneville than McNary Dam, suggesting that affected fish from both tag treatments may have been responding to the implants or to previously latent or newly acquired pathogens and parasites as they migrated downriver. Notably, liver abnormalities were more prevalent in AT fish recaptured at both downstream sites, and splenic enlargement was more prevalent in AT than in PIT-tagged fish recaptured at Bonneville Dam.

Results of comparative histology analyses by tag treatment showed that the incidence of chronic peritonitis was also significantly higher in AT compared to PIT fish. Peritonitis was evaluated locally, at the site of the incision, and may have been a primary reaction to the tag. Although copious bacteria were not observed in the tissue sections examined, the tissue reactivity may have also been elicited by a secondary infection introduced during the surgical procedure or post-operatively through the incision site. Comparative histology results suggested that PIT-tag injection sites had healed cleaner and faster than the surgery incisions.

Similarly, incision apposition was rated as poor more often for AT fish than for PIT fish. Poor or uneven apposition of the two sides of the incision would predispose fish to secondary infections by exposing the underlying dermal tissue to river water, which can be teaming with bacteria and fungi. The AT and/or PIT tags could have introduced bacteria directly into the peritoneal cavity as well. Both sterile and infectious reactions have been observed by others in surgically tagged fish (Brown et al. 2007a; Bunnell and Isely 1999; Chisholm and Hubert 1985; Knights and Lasee 1996; Liedtke et al. 2007; Marty and Summerfelt 1986, 1990; Walsh et al. 2000).

Nutritional indices evaluated grossly, such as caecal and mesenteric adipose, suggested that yearling Chinook salmon were not receiving sufficient nutrition to maintain their metabolic needs as they migrated inriver. Study fish (AT and PIT) recaptured lower in the river were observed to have lower nutritional reserves than those recaptured at more upriver sites. Of interest was the suggestion that AT fish were utilizing these reserves at a greater rate than PIT-tagged fish. These observations, however, were not confirmed by histological assessment of mesenteric adipose, as AT fish were rated as having statistically larger amounts of mesenteric fat at Bonneville Dam than PIT fish. This was not surprising, considering the fact that the histological assessment was conducted on several small pieces of tissue (primarily pyloric caecae and mesenteric tissues surrounding other organs collected) rather than in a whole animal assessment.

In the combined histological analyses between treatments, only lower intestinal mucosal glycogen differed significantly on histological exam (PIT>AT). Other indicators of nutritional status, such as mucosal glycogen stores, were inconsistent in direction for site-specific comparisons between the two treatments. Histological comparisons among size classes for nutritional indices, such as the amount of adipose tissue present and glycogen stores, indicated that larger fish overall were more fit than smaller fish when they reached the downstream recapture sites.

Based on gross necropsy observations, it appeared that AT fish may have experienced higher metabolic loads as they migrated inriver due to the added bulk and weight of the acoustic tags, causing them to utilize caecal and mesenteric adipose to a greater extent than the PIT fish. It is also possible that the acoustic implants acted as mechanical appetite suppressants, although yearling Chinook are not thought to feed heavily as they migrate (Connor et al. 2004). Additionally, the AT fish appeared to be devoting more energy towards inflammatory type responses (gross necropsy observations and results of comparative histology analyses). Immunologic reactions could have been elicited by the acoustic implants or by secondary invaders such as bacteria and fungi, potential byproducts of surgery or delayed healing. Comparative analyses of Rs antigen levels did not indicate that AT fish were more vulnerable to this agent than PIT fish.

Similar to the reference yearling fish sampled at Lower Granite Dam, the subyearling reference fish appeared to be healthy. Aside from a few livers that were grossly discolored, few other abnormalities were noted internally or externally on gross necropsy and histological exam. ELISA testing for Rs antigen revealed low levels in all but a few of the subyearling baseline fish. Grossly visible external lesions were also rare in fish recaptured downstream; however, we were only able to obtain 9% of our target sample for the AT fish. This was presumably due to high mortality prior to fish reaching Bonneville Dam.

Internally, indicators of inflammation and/or infection (discoloration in the liver and kidneys) were visible grossly in fish from both treatment groups recaptured downstream. This suggested that affected fish may have been responding to implants or to previously latent or newly acquired pathogens and parasites, similar to the yearling Chinook salmon as they migrated inriver. Also similar to the yearling fish, signs of obvious infection such as large amounts of bacteria or fungi were not observed in tissues sampled for histology.

Evidence of inflammation was greater in AT compared to PIT fish on both gross necropsy exam and histological exam. A higher percentage of AT fish were observed to have generalized liver and kidney discoloration grossly than PIT fish, and both chronic peritonitis and chronic inflammation at the incision were statistically more prevalent in AT fish in the combined histological comparison between treatment groups. Also similar to the yearling fish, comparative histological analyses indicated that injection wounds in PIT fish were healing faster and cleaner than the AT fish incisions (stratum compactum reknitting (PIT>AT) and dermal hemorrhage/fibrin (AT>PIT). Size class comparisons revealed more evidence of inflammation in smaller fish, as indicated by the presence of liver lymphocytic infiltrates compared to larger fish. This metric in particular is used as an indicator of BKD.

Gross necropsy and histological exam indicated that subyearling fish were utilizing rather than building nutritional reserves as they migrated from Lower Granite Dam to Bonneville Dam, and that this phenomenon was more pronounced in the AT than PIT fish. Grossly, caecal and mesenteric adipose tissue were observed to be present in greater amounts in PIT than AT fish. Additionally, mucosal glycogen stores were greater in PIT fish (McNary and Bonneville Dams combined) compared to AT fish as was pancreatic zymogen, a digestive enzyme that is present only when fish have been eating. Differential growth (PIT>AT), although not statistically significant, was also observed in the fish held for long term observation (this study).

Similar to the yearling results, these observations and results indicate that subyearling AT fish likely experienced higher metabolic demands than PIT fish as they migrated inriver. This increased demand may have been due to the added bulk and weight of the acoustic tags or due to the demands of mounting an inflammatory reaction. Overall, the AT fish appeared to be taxed with more inflammatory type reactions than the PIT fish. These reactions could have been elicited by the presence of the acoustic tag or by infection sustained during or post-surgery as fish attempted to heal.

Finally, it is possible that the acoustic implants acted as mechanical appetite suppressants in AT compared to PIT fish. Unlike the yearling fish, subyearlings are thought to feed and grow significantly as they migrate (Connor et al. 2004). Although there was no indication on gross exam that AT fish had stopped eating compared to PIT fish, digestive enzymes were more prevalent on histological exam in the AT fish than the PIT fish. Comparative analyses of Rs antigen levels did not indicate that AT fish were more vulnerable to this agent than PIT fish.

EXTENDED HOLDING OF ACOUSTIC- AND PIT-TAGGED JUVENILE SALMON

Executive Summary

Yearling Chinook Salmon. For extended holding and observation of yearling Chinook salmon, 40 reference fish and 40 fish from each tag treatment (AT and PIT) were subsampled on each of 10 release days during collection and tagging for migration behavior and survival releases (1,200 total). Reference and treatment fish taken at Lower Granite Dam were transported directly to the Bonneville Dam Second Powerhouse Juvenile Monitoring Facility. These fish were held in laboratory tanks for a total of 90 d to observe tag loss, tissue response to tagging, and long-term survival. Fish were tested for the antigen to *Renibacterium salmoninarum* (Rs) using an ELISA. We also collected CWTs from hatchery marked fish in each sample group to examine survival trends within individual hatchery release groups.

For fish held for long-term observation, average survival among the three groups was significantly different ($P = 0.027$) after 14 d. Fisher's LSD testing further revealed that that survival of AT fish (85%) was significantly lower than that of PIT (92%) and reference fish (93%). This difference persisted and continued to be significant ($P = 0.012$) at 28 d. By 90 days of holding, although the trend among treatment groups persisted, differences among group means were no longer significant. Among fish that survived 90 d, average growth was 3.6 mm greater for PIT-tagged than for AT fish, but the difference was not statistically significant ($P = 0.068$).

No yearling Chinook that survived to the end of the 90-d holding period expelled or dropped an acoustic tag. The AT fish that survived to termination dropped PIT tags at a rate of 2.0% ($n = 5$ tags) while PIT-tagged fish that survived to termination dropped PIT tags at a rate of 0.3% ($n = 1$). The difference in PIT-tag loss between treatment groups was not significant ($P = 0.064$). Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the bottoms of the holding tanks, it was not possible to determine the timing of tag loss.

In fish that died before termination of the study, there were no significant differences in Rs antigen levels among treatment groups ($P = 0.774$). There were also no significant differences in Rs levels among treatment groups in fish that survived until experiment termination ($P = 0.993$).

Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias the results.

Subyearling Chinook Salmon. Forty fish from each release and treatment combination (AT, AT pilot, and PIT fish) along with 40 reference fish (anesthetized and handled but not tagged) were subsampled from groups collected and tagged at Lower Granite Dam for studies of migration behavior and survival. Subsamples were taken from 9 subearling release groups (1,440 fish total) and transported directly to the juvenile monitoring facility at Bonneville Dam. These fish were taken throughout the summer study and held at Bonneville in laboratory tanks for 90 d to observe tag loss, tissue response to tagging, long-term survival, and prevalence of Rs antigen. We also collected CWTs from hatchery marked fish to evaluate the potential influence of hatchery fish on survival, as described above for yearling Chinook salmon.

In the laboratory, mean survival among treatment groups at 14 d holding was significantly different ($P = 0.001$). Fisher's LSD testing revealed that survival was significantly lower for AT fish (53%) compared to PIT (94%) or reference fish (88%). A comparison of mean survival among groups including the AT pilot fish also revealed a significant difference at 14 days ($P = 0.000$), with this group showing considerably lower survival (18%) than the other three groups. These differences persisted and continued to be statistically significant through the holding period. Among fish that survived to 90 d, average growth for PIT fish was 4.5 mm more than for the AT fish ($P = 0.061$). The average difference in weight gain for these same fish was 3.4 g ($P = 0.246$).

For subyearlings that survived to the end of the 90-d holding period, 7.6% of AT fish passively dropped or expelled acoustic tags, while none of the AT pilot fish surviving to termination dropped or expelled tags. The AT fish lost PIT tags at a rate of 3.4%, while no PIT tags were lost from the AT pilot fish. Tag loss in the PIT fish was 0.3%. The difference in PIT tag loss between the AT and PIT fish was significant ($P = 0.002$). No significance testing was performed to compare either acoustic- or PIT-tag loss in the AT pilot fish to other treatments due to small numbers of survivors in that group. Similar to the yearling group, tag loss was determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the bottom of the holding tanks, it was not possible to determine the timing of tag loss.

Rs antigen values as measured by an ELISA for subyearling laboratory fish that died before termination of the study ranged from 0.055 to 2.264. There were no significant differences in Rs antigen levels among the treatment groups ($P = 0.584$). Rs antigen levels for fish that survived until experiment termination at 90 d ranged from 0.040 to 0.240. Because nearly all fish held to termination had low levels of RS antigen, significance testing to evaluate differences among groups was not conducted.

Evidence from coded-wire tags collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to cause bias of any study results.

Introduction

During the yearling and subyearling Chinook migration and survival studies, subsamples of each study group were held in laboratory tanks for a total of 90 d to observe tag loss, tissue response to tagging, and long-term survival. Levels of *Renibacterium salmoninarum* (Rs), the bacterial agent responsible for bacteria kidney disease (BKD) were also compared among treatments and between fish that died prior to the end of the holding period vs. fish that survived 90 days. Results of these comparisons were used to determine whether or not acoustic-tagged fish were more suseptable to BKD than PIT-tagged fish. Coded-wire tags were collected from all laboratory fish when present in an attempt to determine whether variations in percent survival were related to individual hatchery release groups.

Methods

Fish Collection, Transport, and Tissue Sampling

Fish allocated for long-term holding and observation were selected from yearling and subyearling release groups tagged at Lower Granite Dam. Subsamples of 120 yearling Chinook salmon (40 AT, 40 PIT, and 40 reference) and 160 subyearling Chinook salmon (40 AT, 40 AT pilot, 40 PIT, and 40 reference) were taken for laboratory holding. Subsamples were taken from 10 of the 10 yearling release groups, for a total of 1,200 fish. Subsamples were taken from 9 of the 27 subyearling release groups tagged at Lower Granite Dam (over the full range of the summer tagging session) for a total of 1,440 fish.

Reference fish were collected at Lower Granite Dam and anesthetized and handled in the same manner as the acoustic-tagged fish; however, no incision, suture, or tag was placed in these fish. Following tagging, laboratory fish were held separately from the "release" fish in one of two 75-L (19.8 gal) stainless steel holding tanks supplied with flow-through river water for 12-24 h. At the end of the holding period, fish were transferred (water-to-water) to a 1,817 L (480 gal) trailer tank containing saline river water (10 ppt) and transported by truck to the juvenile monitoring facility at Bonneville Dam Second Powerhouse. Average time of transport was 6 hours 14 minutes. Water temperatures during individual transports were kept within 1.1°C of the departure temperature by adding jugs containing frozen river water to the tank as needed. Transport temperatures ranged from 10.8 to 12.8°C during the spring and from 15.6 to 20.0°C during the summer.

Upon arrival at the Bonneville facility, fish were transferred (water-to-water) to 1,893 L (500 gal) circular tanks and held by transport group (e.g., 120 fish per tank in spring and 160 fish per tank in summer). In an attempt to mimic the physical conditions that migrating fish experienced inriver, study tanks were maintained with flow-through river water at ambient temperature for 14 d. On day 15, study tanks were converted to a closed artificial seawater system (to mimic ocean conditions), which was maintained through the remainder of the 90-day holding period. The timing of transfer to seawater at 15 days holding was based primarily on yearling travel times (Hockersmith et al. 2007). Subyearling travel times during the summer migration are typically more variable (Conner et al. 2005); however, we also transferred these groups to seawater on day 15 of holding for comparison purposes.

In 2007, travel time to Bonneville Dam for the 50th percentiles of AT and PIT-tagged yearling fish released at Lower Granite Dam was 12.9 and 12.5 d, respectively. Travel time to Bonneville Dam for the 50th percentiles of AT and PIT-tagged subyearling fish released at Lower Granite Dam was 24.1 and 15.5 d, respectively. Freshwater temperature ranged from 10.6 to 21.7°C during spring and from 16.7 to 21.7°C during summer. Seawater holding temperature ranged from 11.1 to 13.3°C throughout both seasons and did not vary by more than 1°C within a 24-hour period. Fish were fed ad libitum a diet consisting of a mixture of appropriately sized *BioDiet Grower*, a semi-moist pelleted commercial fish food (Bio-Oregon). Waste food and fish excrement were removed from holding tanks on a continuous basis by the self-cleaning action of flow within the tanks. Tanks were monitored for dropped tags and mortalities at least twice daily.

At the end of the 90-d holding period, surviving fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004) and weighed and measured. Gross necropsies were performed following the methods outlined by Noga (1996) to evaluate gross tissue response to tagging, such as tag encapsulation. Kidney tissue was collected from each laboratory fish and placed in individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). These samples were frozen and transported on ice to labs at the Northwest Fisheries Science Center, Seattle, WA. Kidney samples were processed and Rs antigen level determined for each fish in the same manner described above for migrating fish recaptured for necropsy and histological exam. Coded-wire tags were collected from the snouts of individual fish when present, and their respective codes were recorded in a database for future reference.

Data Analysis

We estimated laboratory survival at 14, 28, and 90 d post-treatment (Table 22). Comparison at day 14 corresponded with the end of the freshwater holding phase. Comparison at day 28 was included in to identify residual mortality from handling or tagging that may have been dampened by transfer into seawater and/or obscured by background holding mortality by 90 d.

Average survival at 14-, 28-, and 90-days was compared among treatment groups using a 2-factor ANOVA with replicate as a random factor and treatment as a fixed factor. Differences among treatment groups were compared using least significant differences. Growth in mm (yearling and subyearling Chinook) and gain in g (subyearling Chinook) were averaged across samples by replicate for AT and PIT-tagged fish that survived 90-d holding.

Paired *t*-tests were used to compare differences between treatments and across replicates. Levels of Rs antigen present at the time of death were compared among treatment groups both for fish that had died prematurely, and for those that survived the entire 90-d holding period. Statistical comparisons of Rs antigen levels followed the methods outlined above for migrating fish recaptured for necropsy and histological exam.

Differences in the percentage of PIT tags lost between treatments (AT and PIT) for spring and summer groups were evaluated statistically using chi-square tests. Tag loss was compared only for fish that survived to the end of the holding period because for those that died earlier, it was not always possible to determine whether tag loss had occurred pre- or post-mortem. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the bottom of holding tanks, it was not possible to determine the timing of tag loss. Missing tags could have been dropped through an open wound or could have been actively expelled through the body wall.

Results

Yearling Chinook Salmon

Survival—Yearling Chinook salmon exhibited a decline in survival over time (all treatments) throughout the 90-d holding period (Figure 20). For all treatments (reference, AT, and PIT), the downward slope of the survival curve became more gradual after fish were transferred into seawater on day 15. Mortality began to accelerate again after ~56 d of holding and then steadily increased through 90 d for all treatments. Overall, AT fish experienced lower survival throughout the entire 90-d holding period than did reference and PIT fish.

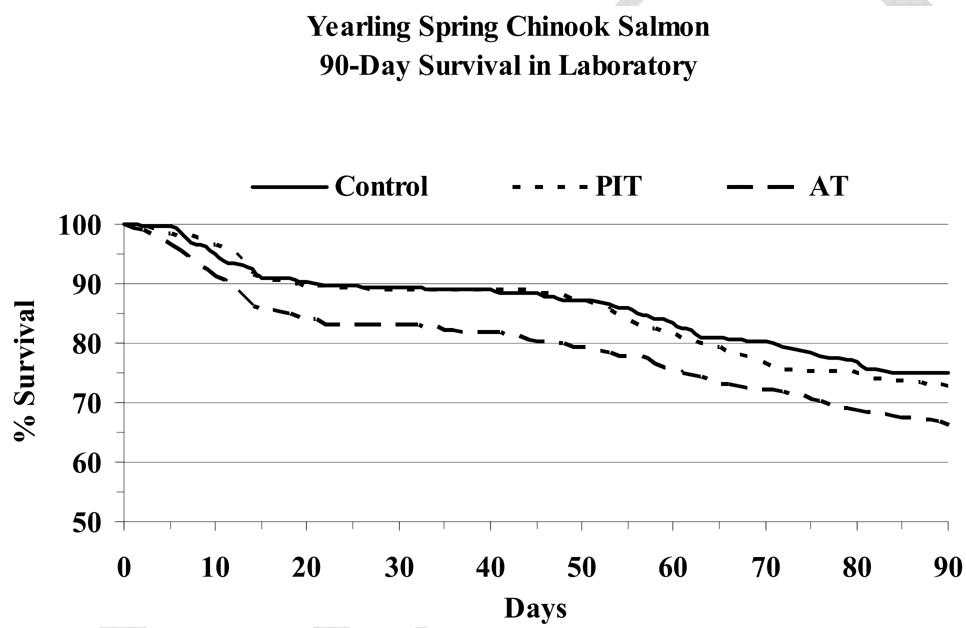


Figure 20. Percentage survival for laboratory fish by treatment through 90 d holding at Bonneville Dam.

Average survival was significantly different ($P = 0.027$) among laboratory study groups after 14 d holding. Further testing based on Fisher's LSD revealed that average survival of AT fish was significantly lower than that of PIT and reference fish.

Average survival among laboratory study groups after 28 d holding was significantly different ($P = 0.012$). Testing based on Fisher's LSD revealed that average survival of AT fish was significantly lower than that of PIT-tagged and reference fish.

Average survival among laboratory study groups after 90 days holding was not significantly different ($P = 0.159$).

Table 21. Percentage survival for yearling Chinook by treatment group (reference, AT, or PIT) after 14, 28, and 90 d holding in the laboratory at Bonneville Dam.

	Yearling Chinook Survival			
Treatment date	Reference	AT	PIT-tag	Total
	14 d holding			
24 Apr	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.02)
25 Apr	0.90 (0.05)	0.88 (0.05)	0.97 (0.03)	0.92 (0.03)
27 Apr	0.95 (0.03)	0.88 (0.05)	0.98 (0.02)	0.93 (0.02)
30 Apr	0.68 (0.08)	0.79 (0.07)	0.84 (0.05)	0.78 (0.04)
2 May	0.95 (0.05)	0.63 (0.011)	0.74 (0.07)	0.77 (0.05)
4 May	0.98 (0.02)	0.95 (0.03)	1.00 (0.00)	0.98 (0.01)
7 May	0.88 (0.05)	0.73 (0.07)	0.83 (0.06)	0.81 (0.04)
9 May	0.98 (0.02)	0.93 (0.04)	0.93 (0.04)	0.94 (0.02)
11 May	1.00 (0.00)	0.85 (0.06)	0.95 (0.03)	0.93 (0.02)
14 May	1.00 (0.00)	0.92 (0.04)	0.98 (0.02)	0.96 (0.02)
Total	0.92 (0.02)	0.86 (0.02)	0.92 (0.02)	0.90 (0.01)
Average	0.93 (0.02)	0.85 (0.02)	0.92 (0.02)	0.90 (0.01)
	28 d holding			
24 Apr	0.95 (0.03)	0.93 (0.04)	0.95 (0.03)	0.94 (0.02)
25 Apr	0.85 (0.06)	0.88 (0.05)	0.92 (0.04)	0.88 (0.03)
27 Apr	0.95 (0.03)	0.85 (0.06)	0.98 (0.02)	0.92 (0.02)
30 Apr	0.66 (0.08)	0.74 (0.07)	0.82 (0.06)	0.74 (0.04)
2 May	0.84 (0.08)	0.53 (0.011)	0.74 (0.07)	0.71 (0.05)
4 May	0.98 (0.02)	0.95 (0.03)	1.00 (0.00)	0.98 (0.01)
7 May	0.79 (0.06)	0.70 (0.07)	0.75 (0.07)	0.75 (0.04)
9 May	0.95 (0.03)	0.88 (0.05)	0.88 (0.05)	0.90 (0.03)
11 May	0.97 (0.03)	0.83 (0.06)	0.93 (0.04)	0.91 (0.03)
14 May	1.00 (0.00)	0.87 (0.05)	0.95 (0.03)	0.94 (0.02)
Total	0.89 (0.02)	0.83 (0.02)	0.89 (0.02)	0.87 (0.01)
Average	0.89 (0.02)	0.81 (0.02)	0.89 (0.02)	0.87 (0.01)
	90 d holding			
24 Apr	0.88 (0.05)	0.75 (0.07)	0.88 (0.05)	0.83 (0.03)
25 Apr	0.75 (0.07)	0.70 (0.07)	0.38 (0.08)	0.61 (0.04)
27 Apr	0.77 (0.07)	0.60 (0.08)	0.88 (0.05)	0.75 (0.04)
30 Apr	0.45 (0.08)	0.63 (0.08)	0.49 (0.07)	0.52 (0.05)
2 May	0.68 (0.011)	0.32 (0.11)	0.44 (0.08)	0.47 (0.06)
4 May	0.78 (0.07)	0.70 (0.07)	0.95 (0.03)	0.81 (0.04)
7 May	0.57 (0.08)	0.45 (0.08)	0.63 (0.08)	0.55 (0.05)
9 May	0.90 (0.05)	0.73 (0.07)	0.85 (0.06)	0.83 (0.03)
11 May	0.79 (0.07)	0.70 (0.07)	0.85 (0.06)	0.78 (0.04)
14 May	0.82 (0.07)	0.85 (0.06)	0.93 (0.04)	0.87 (0.03)
Total	0.74 (0.02)	0.66 (0.02)	0.72 (0.02)	0.71 (0.01)
Average	0.74 (0.04)	0.64 (0.04)	0.73 (0.04)	0.70 (0.01)

Growth—At the end of the 90-d holding period, survivors were measured (FL) and weighed, and growth in mm was calculated for individual fish based on fork length at the time of tagging. Table 23 shows average growth in millimeters for yearling Chinook by tag treatment and date of tagging. For yearling Chinook that survived to the end of the 90-d holding period, average growth was 33.4 mm for AT fish (range 27.5-40.0 mm) and 37.1 mm for PIT-tagged fish (range 33.2-41.9 mm). The average difference in growth between AT and PIT fish was 3.6 mm and was not significant (P = 0.068).

Table 22. Average growth of yearling Chinook by treatment group and date for fish that survived 90 days holding at Bonneville Dam. The difference between averages (3.6 mm) between the two treatment groups was nearly significant (P = 0.068).

	Average yearling Chinook growth (mm)	
Tagging date	AT	PIT
24 Apr	36.5 (2.5)	37.9 (2.3)
25 Apr	36.1 (2.1)	40.2 (2.7)
27 Apr	30.5 (2.9)	41.9 (1.5)
30 Apr	31.0 (2.9)	41.2 (2.6)
2 May	40.0 (5.7)	33.8 (2.5)
4 May	27.5 (2.1)	35.4 (1.8)
7 May	30.2 (3.7)	35.7 (1.9)
9 May	32.8 (2.3)	34.2 (2.2)
11 May	35.6 (2.3)	33.2 (1.7)
14 May	34.3 (2.5)	36.9 (2.1)
Average	33.4 (1.2)	37.1 (1.2)

Tag Expulsion—Yearling Chinook that survived to the end of the 90-d holding period expelled or dropped PIT tags at the rates shown in Table 23. The difference observed between treatment groups was not significant ($P = 0.064$). No yearling laboratory AT fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags.

Table 23. Percentage of dropped or expelled tags by AT and PIT fish held 90 d at Bonneville Dam. Actual number of tags lost is in parentheses. The difference in PIT–tag loss between treatments was not significant ($P = 0.064$).

	AT fish	PIT fish
Lost PIT tag	2.0 (5)	0.3 (1)
Lost AT tags	0.0 (0)	NA

Prevalence of *Renibacterium salmoninarum*—Of the hatchery yearling Chinook salmon held in the laboratory at Bonneville, 334 died before termination of the study. Overall, ELISA values for these fish ranged from 0.060 to 3.709. Coded values for individual ELISA samples were averaged by replicate and treatment (Table 25). The Kruskal-Wallis test to compare treatments yielded a *P*-value of 0.774, indicating no significant difference in BKD levels among Reference, AT, and PIT fish. Coded values averaged around 2.0 across treatments.

Levels of BKD were somewhat lower for the 814 hatchery yearling Chinook salmon that did not die before termination of the study. Overall ELISA values ranged from 0.054 to 3.304. Coded values for individual ELISA samples were averaged by replicate and treatment (Table 26). The Kruskal-Wallis test to compare treatments yielded a *P*-value of 0.993 indicating no significant difference in BKD levels among reference, AT, and PIT fish. Coded levels averaged 1.4 across treatments.

Table 24. Hatchery yearling Chinook salmon ELISA coded values averaged by replicate and treatment for mortalities of fish held at Bonneville juvenile monitoring facility.

Treatment group	Replicate	Sample	ELISA Code Avg
Reference	1	5	2.80
	2	10	1.90
	3	9	2.44
	4	21	2.00
	5	6	2.17
	6	9	2.56
	7	18	1.89
	8	4	1.75
	9	8	1.88
	10	6	1.33
AT	1	10	2.20
	2	11	2.09
	3	16	2.25
	4	14	1.93
	5	13	1.62
	6	12	2.75
	7	22	2.00
	8	11	1.27
	9	12	1.25
	10	6	1.50
PIT	1	5	2.20
	2	24	2.79
	3	5	2.00
	4	23	2.39
	5	22	2.23
	6	2	1.00
	7	15	2.20
	8	6	1.50
	9	6	1.00
	10	3	1.33

	Total	Average
Reference	96	2.1
AT	127	1.9
PIT	111	1.9

Table 25. Hatchery yearling Chinook salmon coded values averaged by replicate and treatment for fish held at Bonneville juvenile monitoring facility and still alive at the termination of the study.

Treatment	Replicate	Number	ELISA Code Avg
Reference	1	35	1.5
	2	30	1.6
	3	30	1.8
	4	17	1.6
	5	13	1.2
	6	31	1.2
	7	24	1.6
	8	36	1.0
	9	30	1.1
	10	28	1.2
AT	1	30	1.6
	2	28	1.5
	3	24	2.0
	4	24	1.9
	5	6	1.2
	6	28	1.3
	7	18	1.4
	8	29	1.0
	9	28	1.1
	10	33	1.1
PIT	1	35	1.5
	2	15	1.5
	3	35	1.7
	4	22	1.8
	5	17	1.2
	6	38	1.3
	7	25	1.7
	8	34	1.0
	9	34	1.0
	10	37	1.1

	Total	Average
Reference	274	1.4
AT	248	1.4
PIT	292	1.4

Influence of Hatchery Fish—All yearling Chinook held at Bonneville were scanned for CWTs post-mortem. Overall, CWTs were identified in nearly 16% of the laboratory fish (n = 180 tags), representing 10 hatchery groups. Table 27 shows the number of CWTs collected by hatchery of origin along with the percent of CWT-tagged fish by hatchery that had either low, medium, or high BKD ELISA values. Figure 21 shows comparative percent survival for yearling laboratory fish with CWTs by hatchery of origin. Overall, our CWT sample numbers were too low for meaningful statistical analysis.

Survival for CWT-tagged yearling fish ranged from 73 to 100%, with one outlier at 0% (hatchery of origin was Lyons Ferry, n = 4). The Lyons Ferry group also had the highest percentage of fish with high ELISA values (75%). The percentage of high ELISA values for the other hatchery groups ranged from 0-44%.

Table 26. Percent survival for yearling laboratory fish with CWTs by hatchery of origin. The percentage of these fish by hatchery that had either a low, medium, or high ELISA value is also indicated along with the total number of CWTs collected.

		ELISA (%)			
Hatchery Origin	Survival	Low	Med	High	Number of CWTs
Clearwater	0.93	0.44	0.37	0.19	27
Dworshak	0.80	0.66	0.20	0.14	35
Kooskia	0.88	0.63	0.13	0.25	8
Lookingglass	0.84	0.66	0.12	0.22	50
Lyons Ferry	0.00	0.25	0.00	0.75	4
McCall	0.73	0.55	0.36	0.09	11
Pahsimeroi	0.75	1.00	0.00	0.00	4
Rapid River	0.75	0.56	0.00	0.44	16
Sawtooth	0.73	0.82	0.00	0.18	11
Umatilla	1.00	1.00	0.00	0.00	1
Unknown	1.00	1.00	0.00	0.00	3

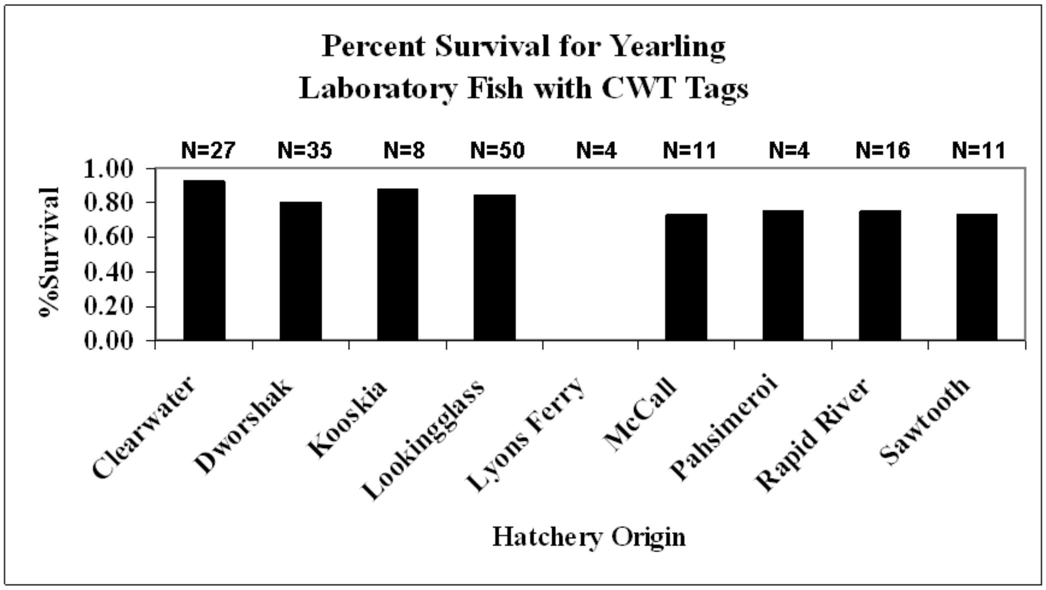


Figure 21. Percent survival during 90-d holding at Bonneville Dam for yearling Chinook with CWTs by hatchery of origin. The actual number of CWTs collected by hatchery is noted above each bar.

It is worth noting that approximately 94.8% of Lyons Ferry Hatchery fish released above Lower Granite Dam were marked with CWTs (Fish Passage Center). Only 4 of the 1,149 fish sampled for holding in the Bonneville laboratory were CWT-tagged fish from Lyons Ferry Hatchery. Assuming equal survival rates to Lower Granite Dam between fish with CWTs and non-tagged fish, the total number of Lyons Ferry Hatchery fish in our laboratory sample (marked and unmarked) would have been about 4 fish. Based on this estimate, it is likely that Lyons Ferry fish represented only about 0.4% of the total number of yearling Chinook subsampled for laboratory evaluations.

Subyearling Chinook Salmon

Survival—A sharp decline in survival was observed from day 0 to day 18 in subyearling Chinook belonging to both the AT and AT-pilot groups. After day 18, mortality continued at a lower rate in these fish until the end of the study. In contrast, the survival curve for both reference and PIT-tagged fish exhibited a shallow decline throughout the entire holding period. The relationship in comparative survival among groups remained constant throughout the entire 90-d holding period.

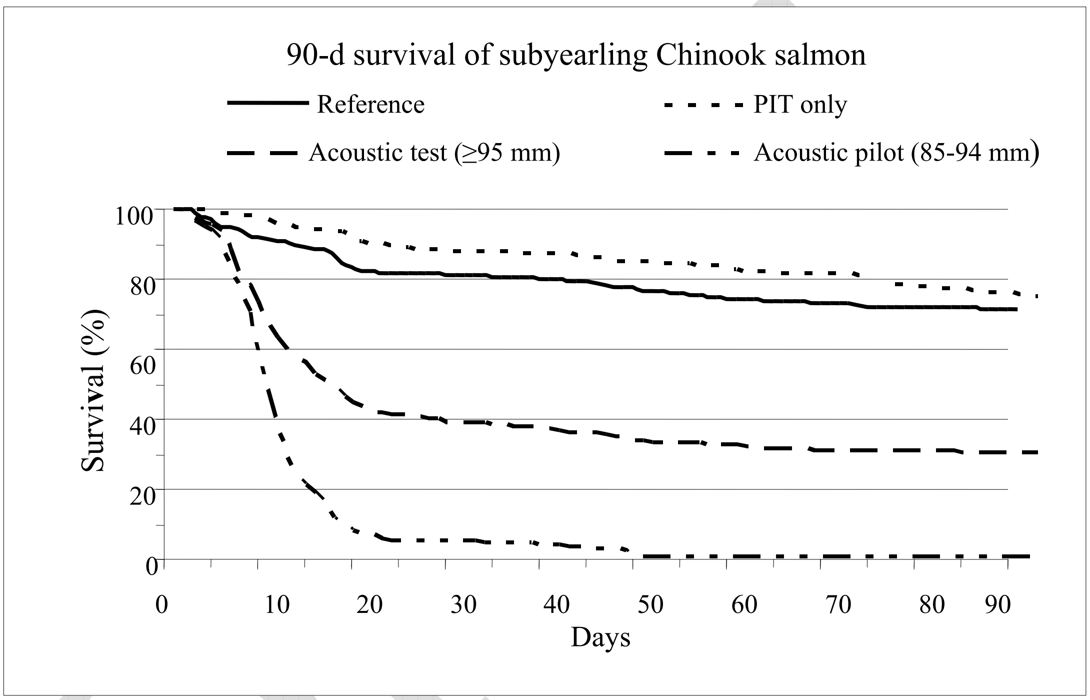


Figure 22. Percent survival for reference, AT, AT pilot, and PIT-tagged fish by treatment during 90-d holding at Bonneville Dam.

The average survival among laboratory groups after 14 d holding was significantly different ($P = 0.00$). Further testing based on Fisher's LSD revealed that the average survival for the AT fish was significantly lower than that of PIT fish and reference fish, and similarly, average survival for AT pilot fish was significantly lower than that of the other three groups. Average survival between the PIT-tagged and reference groups was not significantly different. These significant differences in survival held throughout the entire 90-d holding period.

Table 27. Percent survival of subyearling Chinook by treatment group after 14, 28, and 90 d holding in the laboratory at Bonneville Dam.

	Subyearling Chinook survival				
Treatment date	Reference	AT (≥ 95 mm)	AT pilot (85-94 mm)	PIT	Total
			14 d holding		
6 Jun	0.98 (0.02)	0.92 (0.04)	0.10 (0.05)	1.00 (0.00)	0.75 (0.03)
12 Jun	0.98 (0.02)	0.68 (0.07)	0.10 (0.05)	1.00 (0.00)	0.69 (0.04)
15 Jun	0.97 (0.03)	0.38 (0.08)	0.28 (0.07)	0.95 (0.03)	0.65 (0.04)
19 Jun	0.95 (0.03)	0.43 (0.08)	0.13 (0.05)	0.97 (0.03)	0.62 (0.04)
21 Jun	0.80 (0.06)	0.45 (0.08)	0.11 (0.05)	0.98 (0.02)	0.60 (0.04)
26 Jun	0.95 (0.03)	0.68 (0.07)	0.40 (0.08)	0.93 (0.04)	0.74 (0.03)
28 Jun	0.87 (0.05)	0.73 (0.07)	0.34 (0.08)	0.98 (0.02)	0.73 (0.04)
5 Jul	0.78 (0.07)	0.39 (0.08)	0.13 (0.05)	0.87 (0.05)	0.54 (0.04)
11 Jul	0.73 (0.07)	0.13 (0.05)	0.00 (0.00)	0.83 (0.06)	0.49 (0.04)
Total	0.89 (0.02)	0.53 (0.03)	0.19 (0.02)	0.94 (0.01)	0.65 (0.01)
Average	0.88 (0.04)	0.53 (0.04)	0.18 (0.04)	0.94 (0.04)	0.65 (0.04)
			28 d holding		
6 Jun	0.95 (0.03)	0.69 (0.07)	0.03 (0.03)	0.95 (0.04)	0.66 (0.04)
12 Jun	0.98 (0.02)	0.51 (0.08)	0.08 (0.04)	0.95 (0.04)	0.63 (0.04)
15 Jun	0.82 (0.06)	0.28 (0.07)	0.10 (0.05)	0.90 (0.05)	0.53 (0.04)
19 Jun	0.93 (0.04)	0.35 (0.08)	0.05 (0.03)	0.95 (0.04)	0.57 (0.04)
21 Jun	0.73 (0.07)	0.28 (0.07)	0.08 (0.05)	0.95 (0.03)	0.52 (0.04)
26 Jun	0.95 (0.03)	0.61 (0.08)	0.23 (0.07)	0.86 (0.05)	0.66 (0.04)
28 Jun	0.79 (0.06)	0.58 (0.08)	0.08 (0.04)	0.98 (0.02)	0.61 (0.04)
5 Jul	0.68 (0.07)	0.32 (0.08)	0.03 (0.03)	0.85 (0.06)	0.47 (0.04)
11 Jul	0.51 (0.08)	0.10 (0.05)	0.00 (0.00)	0.60 (0.08)	0.35 (0.04)
Total	0.81 (0.02)	0.41 (0.03)	0.08 (0.01)	0.89 (0.02)	0.56 (0.01)
Average	0.82 (0.03)	0.41 (0.03)	0.07 (0.03)	0.89 (0.03)	0.56 (0.03)
			90 d holding		
6 Jun	0.88 (0.05)	0.62 (0.08)	0.03 (0.03)	0.92 (0.04)	0.62 (0.04)
12 Jun	0.93 (0.04)	0.46 (0.08)	0.03 (0.03)	0.85 (0.06)	0.57 (0.04)
15 Jun	0.59 (0.08)	0.15 (0.06)	0.03 (0.03)	0.80 (0.06)	0.39 (0.04)
19 Jun	0.83 (0.06)	0.35 (0.08)	0.00 (0.00)	0.87 (0.05)	0.51 (0.04)
21 Jun	0.68 (0.07)	0.18 (0.06)	0.03 (0.03)	0.83 (0.06)	0.44 (0.04)
26 Jun	0.85 (0.06)	0.46 (0.08)	0.13 (0.05)	0.74 (0.07)	0.55 (0.4)
28 Jun	0.72 (0.07)	0.45 (0.08)	0.03 (0.03)	0.98 (0.02)	0.55 (0.04)
5 Jul	0.58 (0.08)	0.21 (0.07)	0.00 (0.00)	0.67 (0.08)	0.37 (0.04)
11 Jul	0.37 (0.08)	0.08 (0.04)	0.00 (0.00)	0.33 (0.07)	0.22 (0.04)
Total	0.71 (0.02)	0.33 (0.02)	0.03 (0.01)	0.77 (0.02)	0.47 (0.01)
Average	0.71 (0.04)	0.33 (0.04)	0.03 (0.04)	0.77 (0.04)	0.47 (0.04)

Growth—Average growth in subyearling Chinook surviving to the end of the 90-d holding period was as follows: AT 29.5 mm (range 17.7-39.5) and PIT 34.0 mm (range 27.6-40.0) (Table 29). The average difference in growth between AT and PIT-tagged fish was 4.55 mm and was not statistically significant (*P* = 0.061).

Average weight gain for subyearling Chinook surviving to the end of the 90-d holding period was as follows: AT fish 21.2 g (range 10.3-33.0 g) and PIT fish 24.6 g (range 20.3-28.5 g) (Table 29). The average difference in growth between AT and PIT-tagged fish was 3.4 g and was not statistically significant (*P* = 0.061).

Table 28. Average growth in length and weight for subyearling Chinook by treatment group (AT and PIT fish) and treatment date for laboratory fish that survived 90 d of holding at Bonneville Dam.

	Subyearling Chinook salmon growth	
	AT	PIT
Treatment date	Average increase in length (mm)	
6 Jun	28.2 (11.2)	33.3 (9.2)
12 Jun	31.3 (8.0)	27.6 (9.7)
15 Jun	40.0 (11.4)	34.6 (15.0)
19 Jun	36.6 (11.1)	40.0 (8.0)
21 Jun	25.3 (13.3)	35.5 (5.3)
26 Jun	32.4 (13.2)	36.1 (10.7)
28 Jun	27.8 (14.1)	33.8 (9.5)
5 Jul	26.4 (11.7)	32.2 (9.4)
11 Jul	17.7 (17.7)	32.9 (17.8)
Average	29.5 (1.5)	34.0 (1.5)
	Average increase in weight (g)	
6 Jun	19.2 (9.6)	20.3 (6.8)
12 Jun	22.3 (8.2)	20.6 (8.4)
15 Jun	33.0 (16.6)	20.6 (7.3)
19 Jun	23.4 (5.7)	28.5 (8.6)
21 Jun	17.0 (9.6)	27.5 (6.9)
26 Jun	23.3 (11.2)	25.4 (9.6)
28 Jun	20.9 (11.3)	26.0 (8.9)
5 Jul	21.0 (11.7)	24.5 (9.9)
11 Jul	10.3 (10.1)	27.8 (21.8)
Average	21.2 (1.9)	24.6 (1.9)

Tag Expulsion—Subyearling laboratory fish that survived to the end of the 90-d holding period expelled or dropped PIT tags at the following rates: AT fish 3.4% (n = 4 tags), AT pilot fish 0.0% (n = 0 tags), and PIT fish 0.0% (n = 0 tags)(Table 30). The difference in PIT-tag loss between the AT and PIT fish was significant (*P* = 0.002). Only 10 AT pilot fish survived to study termination; therefore, due to small sample size, we did not statistically compare tag loss in this group to the other treatment groups.

Subyearling laboratory fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags as follows: AT fish 7.6% (n = 9 tags), AT pilot fish 0.0% (n = 0 tags).

Table 29. Percentage of tags dropped or expelled by treatment group (AT, AT pilot, and PIT) from subyearling Chinook laboratory fish during the 90-d holding period at Bonneville Dam. Actual number of tags lost is in parentheses. Chi-square testing revealed a significant difference in PIT tag loss between AT and PIT-tagged fish (*P* = 0.002).

	AT	AT pilot (85-94 mm)	PIT
Lost PIT tags	3.4 (4)	0.0 (0)	0.0 (0)
Lost AT tags	7.6 (9)	0.0 (0)	NA

Prevalence of *Renibacterium salmoninarum*—Compared to the yearling study fish, BKD levels as measure by ELISA were somewhat lower, but treatment comparisons similar, for the 695 hatchery subyearling Chinook salmon that died before termination of the holding study. Overall ELISA values ranged from 0.055 to 2.264. Coded values for individual ELISA samples were averaged by replicate and treatment (Table 27). The Kruskal-Wallis test to compare treatments indicated no significant difference in ELISA levels between reference, AT, AT pilot, and PIT-tagged fish (*P* = 0.584). Coded values averaged around 1.2 across treatments.

For the 663 hatchery subyearling Chinook salmon held at Bonneville Dam that did not die before termination of the study, BKD ELISA values were low, ranging from 0.040 to 0.240 (with two outliers at 0.308 and 0.419). Since ELISA values for all but a few samples were considered to be low, no statistical analysis was conducted to evaluate differences among tag treatment groups.

Table 30. Hatchery subyearling Chinook salmon ELISA coded values for RS antigen averaged by replicate and treatment for mortalities of fish held at the juvenile monitoring facility at Bonneville Dam.

Treatment	Replicate	Number	ELISA Code Avg
Reference	11	5	1.0
	12	3	1.3
	13	16	1.1
	14	7	1.4
	15	13	1.2
	16	6	1.3
	17	11	1.0
	18	15	1.6
	19	26	1.3
AT	11	15	1.1
	12	22	1.1
	13	30	1.3
	14	24	1.0
	15	30	1.1
	16	18	1.2
	17	22	1.5
	18	29	1.2
	19	32	1.3
AT pilot	11	38	1.3
	12	37	1.2
	13	35	1.1
	14	35	1.1
	15	35	1.1
	16	30	1.1
	17	34	1.4
	18	33	1.4
	19	15	1.5
PIT	11	3	1.0
	12	6	1.3
	13	8	1.1
	14	5	1.0
	15	7	1.1
	16	11	1.0
(not used)	17	1	1.0
	18	12	1.4
	19	26	1.3
Reference	Total/Avg	102	1.3
AT	Total/Avg	222	1.2
AT Pilot	Total/Avg	292	1.2
PIT	Total/Avg	79	1.1

Influence of Hatchery Fish—All subyearling laboratory fish were scanned for CWTs post-mortem. Overall, CWTs were identified in 26% of the laboratory fish (n = 371 tags), representing four hatchery groups. Table 33 shows the number of CWT tags collected by hatchery of origin along with the percentage of CWT-tagged fish by hatchery that had either a low, medium, or high BKD ELISA value. Although we collected approximately twice as many CWTs from subyearling as from yearling Chinook, overall, our sample numbers were still low for the summer fish. Similar to spring, we did not attempt to perform any statistical analysis on this group of fish.

Table 31. Percent survival for subyearling laboratory fish with CWTs by hatchery of origin. The percent of CWT-tagged fish by hatchery that had either a low, medium, or high BKD ELISA value is also indicated along with the total number of tags collected.

		BKD ELISA (%)			
Hatchery Origin	Survival (%)	low	med	high	Number of CWTs
Lyons Ferry	0.95	0.99	0.00	0.01	138
Nez Perce	0.97	0.99	0.00	0.01	193
Umatilla	0.69	0.97	0.00	0.03	36
Oxbow-ID	1.00	1.00	0.00	0.00	3
Unknown	0.00	1.00	0.00	0.00	1

Survival for CWT-tagged subyearling fish ranged from 69 to 100% with one outlier at 0%. Subyearling fish from Umatilla Hatchery tended to have lower survival (69%) than fish from the other three known sources (95-100%). The majority (97-100%) of all CWT-tagged fish had BKD ELISA values that were characterized as low.

Overall, 48.8% of the Umatilla Hatchery subyearling Chinook released to the river were marked with CWTs (Fish Passage Center). Of the 1,407 fish sampled from the laboratory, 36 were CWT-tagged fish from the Umatilla Hatchery. Assuming equal survival to Lower Granite Dam between fish with CWTs and non-tagged fish, we estimate that the total number of Umatilla Hatchery fish in our laboratory sample (marked and unmarked) was about 74 fish. Based on this estimate, it is likely that Umatilla Hatchery fish represented approximately 5.2% of our total subyearling laboratory group.

Discussion

Although laboratory fish appeared to fare better overall than their inriver counterparts, relative survival between tag treatments was the same at 14 d post-tagging for fish held in the laboratory as in fish arriving at Bonneville Dam at about 12 d post-tagging. Similar to our inriver migrating groups, differences in survival between tag treatment groups diverged through approximately 12 d post-treatment. By day 14, the majority of inriver fish had passed the final detection site at Bonneville Dam, precluding any further survival comparison between the two groups based on PIT-tag detections.

Up until the point at which laboratory groups were transferred into seawater, we observed a steady decline in survival among all treatment groups, and progressively larger differences between the AT and PIT fish. The survival curve for the reference group followed that of the PIT-tagged group closely. Once fish were transferred to seawater, however, the steep downward sloping of the survival curve, which had been observed from day 0-16 in all groups, started to level off. Differences in survival between AT, PIT, and reference fish were thereafter noticeably less.

It is possible that fish received a therapeutic benefit from the seawater transfer (Noga 2000), and that this benefited the AT fish to a greater extent than the others. It is equally plausible that the observed decrease in the rate of mortality in AT fish relative to the other treatment groups was due to a "tag effect" or "handling effect" that had run its course. Most likely, our observations can be attributed at least in part to both explanations. Additionally, cumulative mortality in the reference and PIT-tagged groups by 90 d likely diminished the statistical power of the test, resulting in a difference in average survival among groups that was no longer statistically significant at study termination. Differential growth between the AT and PIT fish held at Bonneville Dam was also not significant, although higher mortality in the AT fish relative to the PIT-tagged fish may have biased this comparison.

Yearling Chinook salmon that survived to the end of the 90-d holding period were observed to lose PIT tags at unequal rates, with 2% tag loss in AT fish and 0.3% in PIT-tagged fish. This difference was not statistically significant ($P = 0.06$); however, it was similar in magnitude and direction to the difference in detection rates observed at McNary and Bonneville Dam between AT and PIT fish. Furthermore, histopathology results from the SbyC fish recaptured at McNary and Bonneville Dams indicated that wound/incision healing had advanced at a slower rate in AT than in PIT fish. A delay in incision healing would predispose fish to PIT-tag loss.

Similar to results observed for the SbyC fish collected inriver, a comparison of Rs antigen between treatment groups showed no evidence that AT fish were more predisposed to developing BKD than either PIT or reference fish in both the short-term (mortalities) and long-term (fish surviving to study termination). Finally, although Rs antigen levels in CWT-tagged fish differed by hatchery of origin, there was no evidence that laboratory survival among treatment groups was negatively influenced by one or more hatchery groups of BKD infected fish.

For subyearling Chinook salmon, survival results from the long-term holding study supported results from field evaluations. In the laboratory, we observed significant differences in survival for both AT and AT pilot fish compared to PIT and reference fish throughout the holding period. Furthermore, survival of AT pilot fish was significantly lower than that of AT fish. In addition, although we observed a more or less steady but shallow decline in survival for the PIT and reference fish over time, we observed a sharp decline in survival for both AT and AT pilot fish from 0-18 days post-treatment. As such, although the magnitude of the difference in relative survival between AT and PIT fish continued to grow throughout the holding period, the majority of this difference was apparent at approximately 18 days.

Similar to the spring portion of this study, it appears that by day 18 of holding, either the tag effect had largely run its course, or treatment fish had received a survival benefit from transfer to seawater, with AT fish benefiting to a greater extent relative to PIT and reference fish. In comparison, migrating AT fish were just passing McNary Dam at approximately 2 weeks post-release in 2007, and would have required another 2 weeks to reach ocean seawater.

Unlike the yearling Chinook groups, laboratory survival over time was higher (although not statistically different) in subyearling PIT-tagged compared to the reference fish suggesting that a component of the overall tag effect observed in the summer may have been related to the increased handling or extra anesthetic burden placed on AT fish.

In addition to differential survival, a statistically significant difference in PIT-tag loss was observed in the laboratory for subyearling Chinook that survived to termination. A 7.6% rate of acoustic-tag loss was also observed in these fish. If we assume that fish migrating inriver experience similar rates of tag loss, than we must also assume that survival estimates for AT fish based on either AT- or PIT-tag detections exclusively would be negatively biased.

Finally, based on CWTs and ELISA testing there was no evidence that survival estimates for the subyearling laboratory fish were negatively biased by fish from one or more hatchery groups due to infection with BKD.

CONCLUSIONS AND RECOMMENDATIONS

Recent laboratory studies have shown little to no difference in survival and performance between juvenile Atlantic and Pacific Salmon tagged with acoustic transmitters and those injected with PIT tags for tag burdens in the range of 6.7-8% by weight (La Croix et al. 2004; Brown et al. 2007b; Anglea et al. 2004). Fork length of these study fish varied considerably, from a larger range of 122-198 mm (La Croix et al. 2004; Anglea et al. 2004) to smaller ranges of 93-126 mm for subyearlings and 98-152 mm for yearlings (Brown et al. 2007b).

In field studies as well, similar survival rates were observed between paired releases of AT and PIT-tagged yearling Chinook salmon (Skalski et al. 2003, 2005) from Wells and Rocky Reach Dams to Rock Island Dam on the Columbia River. In 2003, the tag burdens of these AT fish ranged from approximately 2.7 to 4% by weight, while median length of fish in each replicate release group ranged from 156 to 211 mm (Skalski et al. 2003). In 2004, the tag burdens of AT tagged fish ranged from 1.3 to 4.6% (mean 2.5%; Skalski et al. 2004), and average fork length ranged from 110 to 225 mm (median 175 mm).

These results, which encompassed both laboratory and field evaluations, and which also encompassed a broad size-range for Chinook salmon, appeared promising for further development of acoustic telemetry systems. We thus attempted to examine relative survival between AT and PIT-tagged yearling and subyearling Chinook salmon as they migrated downstream past Snake and Columbia River dams.

In 2006, we conducted a pilot study to examine the effects of acoustic tagging on yearling Chinook salmon. However, results for river-run fish were inconclusive due the lack of repetition among release groups and inadequate sample sizes. Therefore, in 2007 we expanded this work to include both field and laboratory experiments to identify differences in behavior, survival, growth, and tag loss. Yearling and subyearling Chinook salmon were surgically implanted with acoustic transmitters and these differences were compared to those of cohorts injected with PIT tags. In addition, diagnostic work was performed on actively migrating and laboratory fish to determine the etiology behind any observed differences in survival or performance. An itemized summary of our findings by life history follows:

Yearling Chinook Salmon

1. Differences in detection probability between AT and PIT fish were evident at the first downstream detection site (~60 km from release). Using the adjusted detection data (PIT + AT detections), mean detection probability at Little Goose Dam was significantly greater for AT than for PIT-tagged fish (AT - PIT = 3%; $P = 0.004$). Results were similar using the non-adjusted data (PIT detections only), wherein mean detection probability at Little Goose Dam was again significantly higher for AT fish (AT - PIT = 5%; $P = 0.002$).

2. Travel time from Lower Granite Dam to each downstream detection site was similar between AT and PIT-tagged fish. A statistically significant difference in mean travel time between tag treatments was found only at John Day Dam (AT - PIT = 0.5 d; $P = 0.041$).

3. Estimates of relative survival (AT/PIT) did not differ significantly from 1.0 from Lower Granite to Little Goose, Lower Monumental, and Ice Harbor Dam. However, relative survival from Lower Granite to McNary Dam was 92% and was nearly significant different than 1.0 ($P = 0.054$). Relative survival was 86% to John Day and 79% to Bonneville Dam, and both estimates were significantly different than 1.0 ($P = 0.010$ and 0.001, respectively).

4. Preliminary results suggest that relative survival (AT/PIT) is likely lower for smaller fish. Further analyses are ongoing and will be reported when complete.

5. Initial co-variable analyses performed to identify significant environmental and biological factors that may have been related to the tag effects observed were inconclusive due to the presence of co-linearity among several of the factors tested. (Appendix F). Additional co-variable analyses will be reported when complete.

6. The overall average PIT tag recovery from upriver bird colonies was 0.9% for AT fish and 1.0% for PIT fish, and the difference between these means was not significant. PIT-tag recovery from estuarine sites was 3.3% for AT fish and 2.7% for PIT fish. Similar to the upriver comparison, the difference between these means was not significant.

7. Gross necropsy of actively migrating fish recaptured at McNary and Bonneville Dams revealed several notable trends. In general, fish collected at downstream locations tended to have less adipose tissue (visible fat) than fish observed at release. At both downstream examination locations, PIT fish contained more adipose tissue than AT fish and a higher percentage of their stomachs contained food. Grossly visible liver abnormalities were more prevalent in AT than in PIT fish.

8. Comparative tissue analyses through histological exam revealed statistically significant differences between AT and PIT fish in three general categories, including nutritional condition, peritoneal inflammation and incision (AT) or injection site (PIT) healing. Indicators of nutritional condition were not consistent in direction and therefore did not support a trend for either treatment group relative to the other.

   Parameters that were examined to evaluate healing and inflammation both at the site of the incision and within the peritoneal cavity showed more evidence of inflammation in AT than PIT fish, and that healing had progressed further in PIT-tagged compared to AT fish at each exam site. Additionally, a larger percentage of the AT fish compared to the PIT fish were observed with splenic congestion (an indicator of stress) at McNary Dam. Analysis by size class for fish recaptured at both McNary and Bonneville Dam revealed a clear pattern in the amount of mesenteric adipose tissue present, with larger fish having more fat. There was also a partial but concise pattern in incision apposition by size class, with better apposition observed in progressively larger fish, and a clear and significant improvement in the progression of healing within the PIT group (larger fish at more advanced stages of healing).

9. Estimated Rs antigen (BKD) levels in hatchery Chinook salmon, as measured by ELISA, ranged from 0.070 to 0.131 for fish sampled at Lower Granite Dam prior to tagging. In hatchery yearling Chinook recaptured at McNary Dam and Bonneville Dam, Rs antigen values were similarly low, ranging from 0.070 to 0.133, and from 0.068 to 0.298, with 2 outliers at 0.463 and 1.613 respectively. Since ELISA values for all but a few fish were considered low, no statistical analyses were conducted to evaluate differences between sites or among treatment groups.

10. In laboratory holding, average survival of AT fish was significantly less than that of PIT and reference fish after 14 d ($P = 0.027$). This difference persisted and continued to be significant ($P = 0.012$) at 28 d. By 90 d of holding, although the trend among treatment groups persisted, differences were no longer significant. There was no difference in survival between PIT and reference groups throughout holding. Among the fish that survived to 90 d, the average difference in growth between AT and PIT fish of 3.6 mm was nearly significant ($P = 0.068$).

11. No yearling laboratory fish that survived to the end of the 90 d holding period expelled or dropped acoustic tags. Yearling AT fish surviving to 90 d dropped PIT tags at a rate of 2.0% (n = 5 tags). PIT fish surviving to 90 d dropped PIT tags at a rate of 0.3% (n = 1). The difference in PIT tag loss between the two groups was not significant ($P = 0.064$).

12. Overall, BKD ELISA values for laboratory fish that died before termination of the holding study ranged from 0.060 to 3.709. Significance testing revealed no significant difference in BKD levels among the different treatment groups ($P = 0.774$). ELISA values for laboratory fish that survived to termination ranged

from 0.054 to 3.304. Significance testing revealed no significant difference in BKD levels between the different treatment groups (P = 0.993).

13. Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias our results.

Subyearling Chinook Salmon

1. In comparisons utilizing adjusted values of detection probability for AT fish (AT and PIT detections), mean detection probability was greater for AT than PIT fish at Little Goose Dam (AT - PIT = 11%; P = 0.001). There was no significant difference in mean detection probability between groups at McNary Dam. We were unable to calculate reliable detection probability estimates for Lower Monumental, Ice Harbor, John Day, and Bonneville Dams due to small numbers of detections at these locations during the summer.

2. Due to the small number of detections for subyearling Chinook belonging to the AT pilot group (85-94 mm FL), we did not attempt to estimate detection probabilities or survival estimates for these fish as they migrated downstream. The small number of detections was presumably due to high mortality in this treatment group.

3. Average survival was significantly higher for PIT than AT subyearling fish from Lower Granite to Little Goose (P = 0.003) and to McNary Dam (P = 0.001).

4. Travel time was significantly longer for AT than PIT subyearling fish from Lower Granite to Little Goose, Lower Monumental, Ice Harbor, and McNary Dam.

5. Preliminary results suggest that relative survival (AT/PIT) is likely lower for smaller fish. Ongoing analyses will be reported when complete.

6. Initial covariable analyses performed to identify significant environmental and biological factors that may have been related to the tag effects observed were inconclusive due to the presence of co-linearity among several of the factors tested (Appendix F). Ongoing covariable analyses will be reported when complete.

7. For subyearling Chinook released before 30 June, the overall average PIT tag recovery from upriver bird colonies was 1.3% for AT fish and 1.7% for PIT fish, and the difference between these means was not significant. PIT-tag recovery from estuarine sites was 2.5% for AT fish and 2.0% for PIT fish. Similar to the upriver comparison, the difference between these means was not significant.

8. Gross necropsy exam of migrating subyearlings recaptured at Bonneville Dam revealed a few notable observations. Similar to the yearling fish, in general, fish recaptured at downstream locations tended to have less adipose (visible fat) than fish observed at release. At downstream locations, PIT fish had more adipose than AT fish. Liver and kidney discoloration and or abnormalities were more prevalent in fish sampled at Bonneville Dam and more prevalent in AT than PIT fish.

9. Results from the comparative histopathology analysis between treatments (AT and PIT) for subyearling Chinook recaptured at Bonneville Dam showed significant differences in 11 of 42 parameters/conditions evaluated. Similar to the yearling results, the differences among treatment groups fell into three general categories of nutritional condition, peritoneal inflammation, and healing at the site of the incision (AT) or injection site (PIT). In general, indicators of nutritional condition such as the presence of intestinal glycogen stores and digestive enzymes were higher for the PIT fish compared to the AT fish.

   A higher percentage of AT than PIT fish were observed to have chronic inflammatory changes within the peritoneal cavity at the site of the incision. Healing at the site of the incision/injection site was more advanced in PIT fish. Analysis by size class for all fish sampled at Bonneville Dam revealed a clear pattern across all sizes for the presence/absence of liver lymphocytic infiltrates. These inflammatory cells were observed more often in smaller fish compared to larger fish. Mesenteric fat was more prevalent in fish 12-13 cm than those 11-12 cm.

10. Baseline Rs antigen levels measured by ELISA from subyearling Chinook sampled at Lower Granite Dam prior to tagging ranged from 0.070 to 0.213. Similarly, ELISA values were low for subyearling Chinook recaptured at Bonneville Dam in fish from both tag treatments, ranging from 0.078 to 0.442, with a median value of 0.095. Since ELISA values for all but a few fish were considered low, no statistical analysis was conducted to evaluate differences between detection sites or among treatment groups.

11. In the laboratory holding study, average survival of AT fish was significantly lower than that of PIT and reference fish after 14 d ($P = 0.001$). Average survival of AT pilot fish was significantly lower than that of the other three treatment groups ($P = 0.000$). These differences persisted and continued to be significant at 28 and 90 d. Among fish that survived to 90 d, the average difference in growth between AT and PIT fish of 4.5 mm was nearly significant ($P = 0.061$). The average difference in weight gain for these same fish of 3.4 g was not significant.

12. Subyearling laboratory AT fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags at the rate of 7.6% (n = 9 tags). PIT-tag loss in these fish was 3.4% (n = 4 tags). No acoustic or PIT-tag loss was observed in AT pilot fish that survived to termination. Tag loss in PIT fish was 0.3% (n = 1) for

fish that survived to termination. The difference in PIT tag loss between AT and PIT fish was significant ($P = 0.002$).

13. Overall, BKD ELISA values for laboratory fish that died before termination of the holding study ranged from 0.055 to 2.264. Significance testing revealed no significant difference in ELISA levels among tag treatment groups ($P = 0.584$). ELISA values for laboratory fish that survived 90 d ranged from 0.040 to 0.240 (with two outliers at 0.308 and 0.419). Since ELISA values for all but a few fish were considered low, no statistical analysis was conducted to evaluate differences among treatment groups.

14. Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias our results.

Overall, results of research conducted in 2007 indicated that there were tagging or handling effects associated with the use of acoustic technology in juvenile Chinook salmon. These effects were manifested as higher mortality in acoustic-tagged fish compared to PIT-tagged fish of both life history types. The magnitude of these effects differed between life history types, as well as between serial release groups, as did the distance from release whereby differences between treatment groups became apparent.

Differences in detection probability, as well as trends toward slower travel times in acoustic-tagged fish, were observed in both life history types, indicating possible behavioral differences between tag treatments. In the laboratory, although not statistically significant, subtle differences in PIT tag loss between the two tag groups (yearling and subyearling Chinook), were also observed, and in some instances were of the direction and magnitude to explain the observed differences in detection probability. Overall, the tag effects observed were more prominent in subyearling fish than in yearling fish (in both active migrants and laboratory fish).

Similar to Skalski et al. (2003; 2005) and Hockersmith et al. (2003), we did not find significant differences in average survival for 10 paired releases of AT and PIT-tagged yearling Chinook groups over a moderate distance from release (~225 km or median travel time of ~8 d). While average survival was similar, we did see considerable variation in relative survival among these 10 paired releases (AT/PIT = 81-100%). Further, environmental data indicated that these release groups had been subjected to different environmental conditions throughout spring, particularly with regard to Snake River flow. Although we have been unable to establish a direct connection between environmental conditions and survival, the survival/flow patterns indicate that a connection is likely. Thus we continue to probe further into potential relationships with further analyses.

Because flow and travel time are generally correlated, we suspect that potential tag effects may be related more to time period spent in the river than to distance travelled, and as such, they may be better predicted by some combination of these time and distance rather than a strict distance measure. For this reason, we cannot yet make definitive predictions or conclusions regarding the exact distance over which AT tagging will have virtually no effect in yearling fish. Furthermore, comparative estimates of detection probability averaged over the 10 yearling Chinook release groups were statistically different (albeit by a small margin) at the first downstream detection site in 2007 (~60 km/median travel time ~4 d). This suggested that a behavioral difference may exist that was manifested prior to the observed differences in survival

Average rates of survival, detection probability, and travel time were different between the 10 paired releases of AT- and PIT-tagged subyearling Chinook, and these differences were statistically significant at the first detection site downstream from release (~60 km/median travel time 5.2 d for AT and 3.9 d for PIT). Nevertheless, trends in the data also suggested that the tag effect observed in subyearling Chinook may have been influenced by additional variables such as flow, temperature, and/or size of fish at tagging, rather than by distance traveled alone. As such, similar to the yearlings, the appropriate use of contemporary acoustic tags in subyearling Chinook may be better predicted through some combination of these variables than by distance alone.

Possible etiologies behind the effects observed in acoustic-tagged fish relative to PIT-tagged fish appeared to be consistent between yearling and subyearling fish. Compared to PIT tags, acoustic tags were more likely to elicit an inflammatory response both within the peritoneal cavity and at the incision site. Furthermore, it appeared that acoustic tags either interfered with nutrient intake, or the additional tag burden placed a higher metabolic demand on fish. Additionally, our results indicated that adverse effects were also related to the surgical tagging procedure and were manifested as slower healing compared to PIT-tag injection wounds. These effects were likely amplified in subyearling fish relative to yearling fish due to their being smaller, more metabolically active, and migrating during less favorable environmental conditions.

Subyearling fish are known to feed at higher rates during downstream migration than yearling fish (Conner et al. 2004), and in general, their flesh appears more prone to swelling and tearing. Fish that are actively feeding might place more pressure on an incision than those that are fasting or feeding less rigorously, and pressure on the incision may interfere with healing or lead to full-blown wound dehiscence. Furthermore, subyearling fish are collected and tagged when the river is becoming warmer and fish are more biologically active. These factors made it more likely for subyearling fish to drop or expel tags, contract infections at the incision site, or succumb to other stressors incurred during handling at higher rates compared to yearling fish.

Initial results of our study suggest that both yearling and subyearling Chinook with acoustic implants may experience lower survival, and may behave differently and/or be detected differently than PIT-tagged fish at variable distances from release, depending on travel conditions. In 2008, tagging experiments, including both releases to the river and long-term holding of yearling Chinook, were repeated. These later experiments were conducted, at least in part, amid more normal river flow conditions. In addition, long-term holding experiements using subyearling Chinook were conducted under cooler water temperatures compared to 2007.

In 2008, we also photographed migrating acoustic-tagged fish prior to release and laboratory holding fish both before and after treatment. These photographs may help to identify external physical abnormalities, which in turn may provide information on how fish condition at the time of tagging (e.g., percentage of descaling) influences survival. We included an additional reference group in both the yearling and subyearling long-term holding experiments to represent fish subjected to the surgical process (incision and suture placement) but not the additional burden of an acoustic tag. An additional experimental group was included in the subyearling laboratory holding study to identify whether potential dip treatments, such as hydrogen peroxide, promoted surgical-tag incision healing. These subyearling fish are being monitored and their healing photographed weekly.

Analyses of additional data collected in 2008 and multivariate analyses of 2 years of data will aid in the interpretation of comparisons between AT and PIT-tagged fish, given the dissimilar environmental conditions observed between years. These analyses may provide more definitive conclusions and allow more specific recommendations regarding the effects of contemporary acoustic-tagging procedures on juvenile Chinook salmon. Ideally, we will be able to identify groups of fish by fork length, length of river reach, time in river, or environmental conditions (e.g., temperature or flow) so that these critical variables can be considered in estimates of survival for acoustic-tagged fish.

Finally, many test results reported herein verged on being statistically significant. Therefore, in future studies of this kind we recommend increasing sample sizes to increase the power of the tests to be able to detect true differences if they exist at $\alpha = 0.05$. Interestingly, we also found evidence of abnormalities in PIT-tagged fish during histological examinations that warrant further investigation with respect to the potential effects of PIT tags on adult return rates.

ACKNOWLEDGEMENTS

The collaborative effort of multiple agencies and people led to successful completion of this work, and we express gratitude to all who contributed. We especially thank M. Brad Eppard for his insight and assistance coordinating research activities and the Portland District U.S. Army Corps of Engineers for funding this research. For help in the field, we thank PNNL researchers and technicians Kathleen Carter, Brian Bellgraph, Jennifer Panther, Matt Bleich, Abby Welch, John Stephenson, James Hughes, Shon Zimmerman, Nathan Phillips, Katie Ovink, Jen Monroe, Carmina Arimescu, Scott Titzler, Corey Duberstein and Katie Murray. Field help was also provided by NOAA Fisheries research staff Jason Everett, Neil Paasch, Lynn McComas, and Ken McIntyre.

For their assistance in the field and laboratory, we express much gratitude to Pacific States Marine Fisheries Commission researchers and technicians Larry Basham, Lila Charlton, Chris Eaton, Ethan Ellsworth, Cheryl Engle, and Laura Leighton. We express our appreciation to Scott Davidson, and the entire NOAA Pasco Shop for providing critical logistics for tagging and subsampling, without which this work would not have been possible. We also thank Doug Marsh of NOAA Fisheries for his invaluable assistance and guidance

We thank his Pacific States Marine Fisheries crew for collecting and sorting fish and for tagging reference fish for this study. To Brenda James, Paul James, Andrew Puls, Kara Prather, and Keith Pitts of Cascade Aquatics, thanks for activating and delivering the acoustic tags. Thank also to Peter Kuechle of Advanced Telemetry Systems for sharing his expertise.

Thanks to Mike Halter of USACE and his staff at Lower Granite Dam for helping to coordinate this work and collect fish. For their assistance and advice, we thank Fred Mensik, Doug Ross, and Shawn Rapp of the Washington Department of Fish and Wildlife Smolt Monitoring Program at Lower Granite Dam. We express appreciation to Dave Marvin of the Pacific States Marine Fisheries Commission for making possible our subsampling using the SbyC system. Thanks also to USACE project biologists Brad Eby (McNary Dam), Ben Hausmann (Bonneville Dam), and Jonathon Rerecich (Bonneville Dam), and Dean Ballanger (SMP Bonnville Dam) for assistance in coordinating the SbyC and laboratory work conducted at these facilities.

We thank John Skalski and Rebecca Buchanan of the University of Washington for lending their statistical expertise for the analysis of both PIT- and acoustic-tag detection data. We thank USACE project biologist Greg Moody (Little Goose Dam) and

ODFW biologists Ruth Shearer and Annie Dowdy for their attention and support at Little Goose Dam. We thank Kathleen Moyer with ODFW for providing predation information. Thanks also to Dave Hurson and John Bailey of the Walla Walla District USACE.

We also thank Kenneth Ham, Dennis Dauble, Gayle Dirkes, Kathy Lavender, David Geist, Julie Hughes, Craig Allwardt, and R. Eric Robinson of PNNL. We thank Tom Ruhle, Kinsey Frick, and John Ferguson of NOAA Fisheries for their council and administrative support. Finally, we express our gratitude to JoAnne Butzerin for her insight and assistance in editing this report.

REFERENCES

Absolon, R. F., M. B. Eppard, B. P. Sandford, G. A. Axel, E. E. Hockersmith, and J. W. Ferguson. 2003. Effects of turbines operating at two different discharge levels on survival and condition of yearling Chinook salmon at McNary Dam, 2002. Report to U.S. Army Corps of Engineers, Contract W68SBV20655422. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Acolas, M. L., J. M. Roussel, J. M. Lebel, and J. L. Bagliniere. 2007. Laboratory experiment on survival, growth and tag retention following PIT injection into the body cavity of juvenile brown trout (*Salmo trutta*). Fisheries Research 86:280-284.

Adams, N. S., D. W. Rondorf, and E. E. Kofoot. 1996. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1996 surface bypass collector tests. Report to the U. S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA.

Adams, N. S., D. W. Rondorf, and E. E. Kofoot. 1997. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1997 surface bypass collector tests. Report to the U. S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA.

Adams, N. S., D. W. Rondorf, S. D. Evans, J. E. Kelly, and R. W. Perry. 1998a. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55:781-787.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998b. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 127:128-136.

Anglea, S. M., D. R. Geist, R. S. Brown, K. A. Deters, and R. D. McDonald. 2004. Effects of Acoustic Transmitters on Swimming Performance and Predator Avoidance of Juvenile Chinook Salmon. North American Journal of Fisheries Management 24:162-170.

Anglea, S., T. Poe, and A. Giorgi. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at John Day Dam (1980-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004a. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004b. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Berggren, T. J., and M. J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. North American Journal of Fisheries Management 13:48-63.

Bridger, C. J., and R. K. Booth. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science 11:13-34.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Brown, R. S., D. R. Geist, K. A. Deters, and A. Grassell. 2006. Effects of surgically implanted acoustic transmitters >2% of body mass on the swimming performance, survival and growth of juvenile sockeye and Chinook salmon. Journal of Fish Biology 69:1626-1638.

Brown, R. S., K. M. Carter, K. A. Deters, D. R. Geist, G. A. McMichael, C. A. McKinstry, and R. Elson. 2007a. Evaluation of growth, survival, tag expulsion, and tissue reaction in acoustic-tagged juvenile salmonids *in* Hockersmith et al. 2007. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ60441152. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Brown, R. S., K. M. Carter, K. A. Deters, and C. A. McKinstry. 2007b. Determination of a minimum fish size for implantation with a Juvenile Salmonid Acoustic Telemetry System (JSATS) tag. *In* Hockersmith et al. 2007. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ60441152. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Bunnell, D. B. and Isely, J. J. 1999. Influence of Temperature on Mortality and Retention of Simulated Transmitters in Rainbow Trout. North American Journal of Fisheries Management 19:152-154.

Chisholm, I. M. and Hubert, W. A. 1985. Expulsion of Dummy Transmitters by Rainbow Trout. Transactions of the American Fisheries Society 114:766-767.

Connor, W. P., Smith, S. G., Andersen, T., Bradbury, S. M., Burum, D. C., Hockersmith, E. E., Schuck, M. L., Mendel, G. W., and Bugert, R. M. 2004. Postrelease Performance of Hatchery Yearling and Subyearling Fall Chinook Salmon Released into the Snake River. North American Journal of Fisheries management 24: 545-560.

Conner, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, D. Ross. 2005. Two alternative juvenile life history types for fall Chinook salmon in the Snake River Basin. Transactions of the American Fisheries Society 134:291-304.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51:429-438.

Dare, M. R. 2003. Mortality and long-term retention of passive integrated transponder tags by spring Chinook salmon. North American Journal of Fisheries Management 23:1015-1019.

Elliott, D. G., and R. J. Pascho. 1991. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1989 (Contract E86880047) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA. 305 p.

Elliott, D. G., and R. J. Pascho. 1993. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1991 (Contract E86910058) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA. 179 p.

Elliott, D. G., and R. J. Pascho. 1994. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1992 (Contract E86920048) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA. 202 p.

Eppard, M. B., G. A. Axel, B. P. Sandford, and G. M. Matthews. 1998. Ice Harbor Dam spill efficiency determined by radio telemetry, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Eppard, M. B. , E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002. Spillway survival for hatchery yearling and subyearling Chinook salmon passing Ice Harbor Dam, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005a. Spillway passage survival of hatchery yearling and subyearling Chinook salmon at Ice Harbor Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005b. Spillway passage survival of hatchery yearling Chinook salmon at Ice Harbor Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Gessel, M. H., J. G. Williams, D. A. Brege, R. F. Krcma, D.R. Chambers. 1991. Juvenile salmonid guidance at the Bonneveille Dam Second Powerhouse, Columbia River, 1983-1989. North American Journal of Fisheries Management 11: 400-412.

Giorgi, A. E., G. A. Swan, W. S. Zaugg, T. C. Coley, T. Y. Barila. 1988. Susceptibility of Chinook salmon smolts to bypass systems at hydroelectric dams. North American Journal of Fisheries Management 8: 25-29.

Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays, and C. M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River basin. North American Journal of Fisheries Management 17:268-282.

Goede, R. W., and B. A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. American Fisheries Society Symposium 8:93-108.

Greenstreet, S. P. R., and R. I. G. Morgan. 1989. The effect of ultrasonic tags on the growth rates of Atlantic salmon *Salmo salar* L., parr of varying size just prior to smolting. Journal of Fish Biology 35:301-309.

Hensleigh, J. E., H. C. Hansel, R. S. Shively, R. E. Wierenga, J. M. Hardiman, R. H. Wertheimer, G. S. Holmberg, T. L. Martinelli, B. D. Leidtke, R. E. Wardell, and T. P. Poe. 1997. Movement and behavior of radio-tagged yearling Chinook salmon and steelhead in John Day, the Dalles, and Bonneville dam forebays. Preliminary report to the U. S. Army Corps of Engineers, Portland, OR.

Hockersmith, E. E., S. G. Smith, W. D. Muir, B. P. Sandford, J. G. Williams, and J. R. Skalski. 1999. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hockersmith, E. E., W. D. Muir, S. G. Smith, B. P. Sandford, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling chinook salmon in the snake and Columbia rivers. North American Journal of Fisheries Management 23:404-413.

Hockersmith, E. E., G. A. Axel, M. B. Eppard, D. A. Ogden, and B. P. Sandford. 2005. Passage behavior and survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2004. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., R. S. Brown, and T. L. Liedtke. 2007. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ60441152. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hollander, M. and I. Wolfe. 1973. Nonparametric Statistical Methods. 503 p. Wiley and Sons, New York.

Jepsen, N., A. Koed, E. B. Thorstad, and E. Baras. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483:239-248.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration–stochastic model. Biometrika 52:225-247.

Kaseloo, P. A., A. H. Weatherley, J. Lotimer, and M. D. Farina. 1992. A biotelemetry system recording fish activity. Journal of Fish Biology 40:165-179.

Knights, B. C., and B. A. Lasee. 1996. Effects of implanted transmitters on adult bluegills at two temperatures. Transactions of the American Fisheries Society 125:440-449.

Lacroix, G. L., D. Knox, and P. McCurdy. 2004. Effects of implanted dummy acoustic transmitters on juvenile Atlantic salmon. Transactions of the American Fisheries Society 133:211-220.

Liedtke, T. L., L. P. Gee, M. G. Mesa, J. W. Beeman, D. G. Elliot, and C. M. Conway. 2007. Evaluation of predator avoidance ability, tag loss, and tissue response of acoustic-tagged juvenile salmonids. *In* Hockersmith et al. 2007. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ60441152. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Lucas, M.C. 1989. Effects of implanted dummy transmitters on mortality, growth and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson. Journal of Fish Biology 35:577-587.

Luna, L. G. 1968. Manual of histological staining methods of the Armed Forces Institute of Pathology. McGraw-Hill, New York.

Martinelli, T. L., H. C. Hansel, and R. S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia 371/372:79-87.

Marty, G. D., and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society 115:577-589.

Marty, G. D. and Summerfelt, R. C. 1990. Wound Healing in Channel Catfish by Epithelialization and Contraction of Granulation Tissue. Transactions of the American Fisheries Society 119:145-150.

Maynard, D. J., D. A. Frost, F. W. Waknitz, and E. F. Prentice. 1996. Vulnerability of marked age-0 steelhead to a visual predator. Transactions of the American Fisheries Society 125:330-333.

McComas, R. L., D. Frost, S. G. Smith, J. W. Ferguson, T. Carlson, and T. Aboellail. 2005. A study to estimate juvenile salmonid survival through the Columbia River estuary using acoustic tags, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Mood, A. M., F. A. Graybill, and D. C. Boes. 1974. Introduction to the Theory of Statistics, Third Edition. 564 p. McGraw-Hill. New York.

Moore, A., I. C. Russell, and E. C. E. Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behaviour and physiology of juvenile Atlantic salmon, Salmo salar L. Journal of Fish Biology 37:713-721.

Murchie, K. J., S. J. Cooke, and J. F. Schreer. 2004. Effects of radio-transmitter antenna length on swimming performance of juvenile rainbow trout. Ecology of Freshwater Fish 13:312-316.

Newby, N. C., T. R. Binder, and E. D. Stevens. 2007. Passive Integrated Transponder (PIT) tagging did not negatively affect the short-term feeding behavior or swimming performance of juvenile rainbow trout. Transactions of the American Fisheries Society 136:341-345.

Noga, Edward J. 1996. Fish Disease–Diagnosis and Treatment. Mosby Year Book Inc., St. Louis, Missouri.

Ogden, D. A., E. E. Hockersmith, M. B. Eppard, G. A. Axel, and B. P. Sandford. 2005. Passage behavior and survival for river-run subyearling Chinook salmon at Ice Harbor Dam, 2004. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Ombredane, D., J. L. Bagliniere, and F. Marchand. 1998. The effects of passive integrated transponder tags on survival and growth of juvenile brown trout (*Salmo trutta* L.) and their use for studying movement in a small river. Hydrobiologia 371/372:99-106.

PSMFC (Pacific States Marine Fisheries Commission). 1996. Columbia Basin PIT tag information system (PTAGIS). Pacific States Marine Fisheries Commission, Gladstone, Oregon. Available at www.ptagis.org/ptagis/index.jsp (December 2008).

Pascho, R. J. and D. Mulcahy. 1987. Enzyme-linked immunosorbent assay for a soluble antigen of *Renibacterium salmoninarum*, the causative agent of salmonid bacterial kidney disease. Canadian Journal of Fisheries and Aquatic Sciences 44:183-191.

Pascho, R.J., D.G. Elliott and J.M. Streufert. 1991. Brood stock segregation of spring Chinook salmon *Onchorhynchus tshawytscha* by use of the enzyme-linked immunosorbent assay (ELISA) and the fluorescent antibody technique (FAT) affects the prevalence and levels of *Renibacterium salmoninarum* infection in progeny. Diseases of Aquatic Organisms 12:25-40.

Perry, R. W., N. S. Adams, D. W. Rondorf. 2001. Buoyancy compensation of juvenile Chinook salmon implanted with two different size dummy transmitters. Transactions of the American Fisheries Society 130: 46-52.

Ploskey, G., T. Poe, A. Giorgi, and G. Johnson. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at the Dalles Dam (1982-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Prentice, E. F., T. A. Flagg, and S. C. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Pages 317-322 in Parker et al. (1990).

Roberts, R.J., A. MacQueen, W.M. Shearer, and H. Young. 1973. The histopathology of salmon tagging III. Secondary infections associated with tagging. Journal of Fish Biology 5:621-623.

Seber, G. A. H. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., R. L. Townsend, A.E. Giorgi, and J. R. Stevenson. 1998. The design and analysis of salmonid tagging studies in the Columbia River Basin. Volume XI: Recommendations on the design and analysis of radiotelemetry studies of salmonid smolts to estimate survival and passage efficiencies. Draft report to Bonneville Power Administration, Project 89-107.

Skalski, J. R., R. L. Townsend, T. W. Steig, J. W. Horchik, G. W. Tritt, and A. Grassell. 2003. Estimation of survival of yearling chinook salmon smolts the Rock Island Dam, pool, and project in 2002 using acoustic and PIT-tag release-recapture methods. Report by Columbia Basin Research to Chelan Co. PUD, Wenatchee, WA, 87 pp.

Skalski, J. R., R. L. Townsend, T. W. Steig, P. A. Nealson, K. K. Kumagai, and A. Grassell. 2005. Estimation of survival of yearling and subyearling Chinook, and sockeye salmon smolts, and steelhead at Rocky Reach and Rock Island Projects in 2004 using acoustic and PIT-tag release-recapture methods. Report to the Public Utility District No. 1 of Chelan County, Wenatchee, Washington.

Smith, S. G., W. D. Muir, E. E. Hockersmith, R. W. Zabel, R. J. Graves, C. V. Ross, W. P. Connor, and B. D. Arnsberg. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. North American Journal of Fisheries Management 23:939-961.

Smith, S. G., J. R. Skalski, W. Sclechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH. 1. Manual developed by the Center for Quantitative Science, School of Fisheries, University of Washington for the Bonneville Power Administration. Portland, Oregon.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical methods. Iowa State College Press, Ames, Iowa.

Stein, C., D. Marvin, J. Tenney, and N. Gruman. 2004. 2004 PIT tag specification document. Report to the PIT Tag Steering Committee. 152 p.

Summerfelt, R. C., and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213-263 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

Thorsteinsson, V. 2002. Tagging methods for stock assessment and research in fisheries. Report of Concerted Action FAIR CT.96.1394 (CATAG). Reykjavik Marine Research Institute Technical Report (79).

URF (Use of Fishes in Research) Committee. 2004. Guidelines for the use of fishes in research. American Fisheries Society, Bethesda, Maryland.

Vigg, S., and C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 48: 2491-2498.

Walsh, M. G., A. K. Bjorgo, and J. J. Isely. 2000. Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid striped bass. Transactions of the American Fisheries Society 129:539-544.

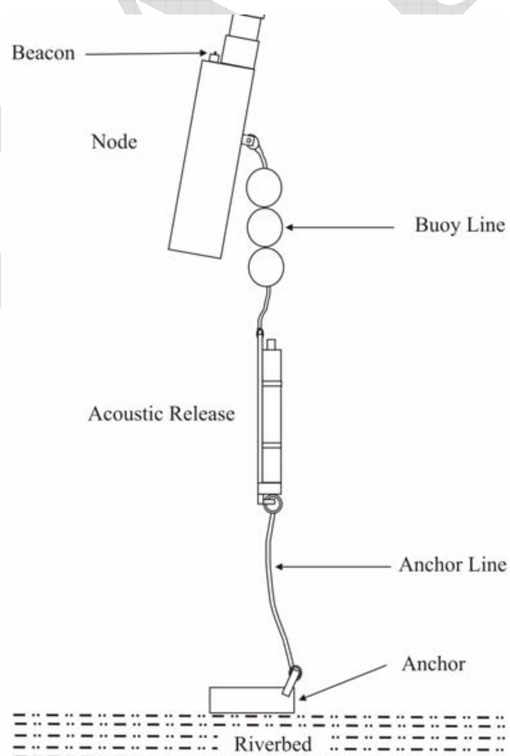
Winter, J. D. 1983. Underwater biotelemetry. Pages 371-395 *in* L.A. Nielsen and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* Murphy, B.R. and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

APPENDIX A

Acoustic Receiver Arrays

Autonomous receiving nodes (Model N201, Sonic Concepts, Inc.) was composed of electronics, on-board power, data storage (CF card), and a hydrophone housed in a 1.2-m long by 15-cm diameter PVC tube. Nodes were deployed to detect and record the presence of passing fish bearing JSATS acoustic transmitters. Each autonomous node consisted of a hydrophone, battery compartment, beacon transmitter, buoy line, acoustic release (Model 111, InterOcean Systems Inc.), anchor line, and anchor (Appendix Figure A1). Beacons emitted a signal every 15 seconds, which confirmed that hydrophones were working properly. Depending on water depth, each acoustic release was shackled to a 35-kg anchor with either a 1.5- or 3.6-m long shock-corded mooring (Appendix Figure A1).



Appendix Figure A1. Diagram of the orientation of an autonomous node and rigging as it was deployed in the river.

Each receiver underwent a rigorous acceptance testing protocol prior to delivery from the manufacturer and deployment in the field. A gross examination was completed to ensure that all parts were present and properly labeled. The nodes were then activated, and basic function was evaluated including proper calibration of pressure and temperature sensors and the system clock, and that the node was able to properly receive, decode, and store acoustic signals to the CF card. Node performance was measured and the housing was tested for leaks. This was done in a small, portable tank lined with anechoic material, using a signal generator and attenuator to simulate range. Each node was placed in the tank approximately 6 feet from the signal generator element. An attenuation curve was created by calculating the percentage of transmissions that were correctly detected and decoded at each of 6 signal levels (i.e., -40, -50, -55, -60, -65, and -70 dB). Acceptance criteria required detection efficiency of 50% or higher at the -40, -50, and -55 dB levels. Nodes that failed any of the test protocols were returned to the manufacturer for repair or replacement and were retested prior to use in the field.

Nodes were deployed in a line perpendicular to the river channel and placed well within their maximum detection range of 300 m to provide detection coverage across the full width of the river at each location.

Receivers were recovered and serviced bi-weekly throughout the study period. To recover each node, the boat was situated close to the waypoint of the node which was displayed on a laptop computer using Fugawi Marine ENC (Northport Systems Inc.) map software. A command unit and transducer (Model 1100E, InterOcean Systems Inc.) were used to activate the acoustic release. Upon receiving the signal from the command unit, the acoustic release opened and released the ring on the anchor line (Appendix Figure Y2) which allowed the node and release to float to the surface. The node and release were recovered from the river and the data file was cursorily examined to determine if the node had been collecting data properly. The node was then connected to a laptop computer and the node clock synchronized with GPS.

Data collection was observed in real time using the beacon transmitter on the node body to confirm at least 3 consecutive detections. The acoustic release was re-armed using two hand-held magnets to activate the motor to close the link to a new anchor line attached to a new anchor. Using GPS and Fugawi, the boat was positioned as close to the previous deployment point as possible, then the re-activated node was lowered to the bottom using a rope fed through the anchor handle to control its decent. As nodes were deployed a new waypoint was created and the time, depth, and the latitude and longitude were recorded.

Data collected by the autonomous nodes were recorded as a single text file on CF cards. Physical data (i.e., date, time, pressure, water temperature, tilt, and battery voltage) were written to file every 15 seconds. Valid acoustic transmitter detection data were recorded as they were received. Detection data included individual transmitter code, time stamp, receive signal strength indicator, and a calculated measure of background noise (i.e., RxThreshold). Each data file was transferred to a laptop computer following servicing or retrieval events.

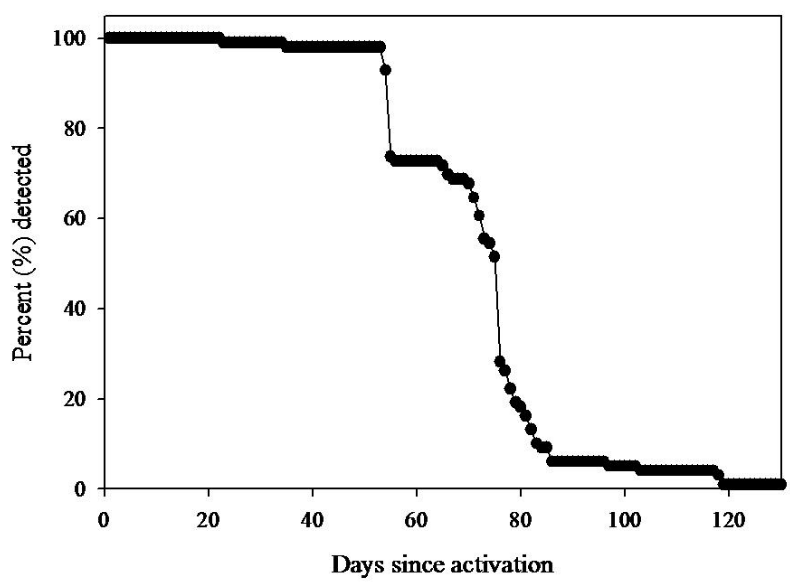
Data files from all nodes were coded with the node location and stored in a database developed specifically for storing and processing acoustic telemetry data. To filter out false positives (i.e., detections of otherwise valid tag codes that were not in the set of codes implanted in fish), a post-processing program was implemented. This program was comprised of a sequence of steps that compared each transmitter detection to a list of transmitters that were released and then compared the detection date to the release date. Only detections from the list of released transmitters that were detected after they were released were retained for analysis. A minimum of 4 detections in 120 seconds was required, and only detection events with the correct time spacing were retained in the valid detection file. From the valid detection file, a detection history was created for each fish, which was used to estimate detection probability and survival.

APPENDIX B

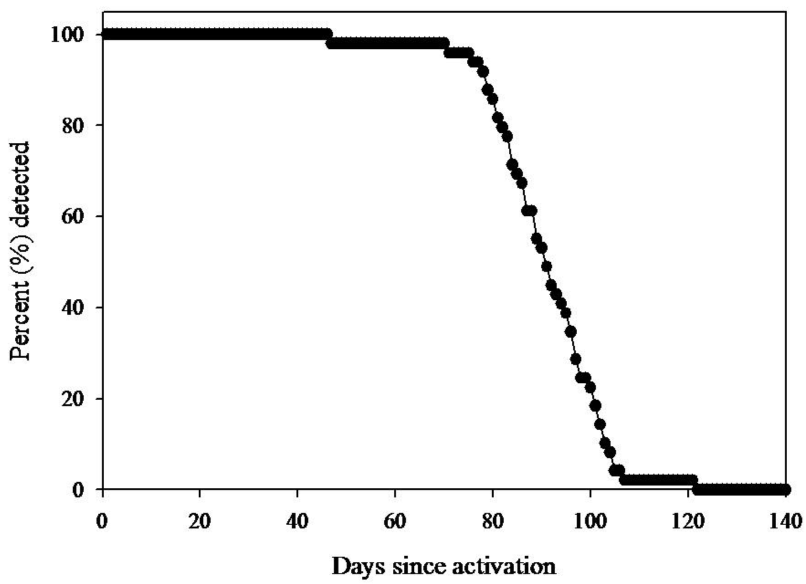
Transmitter Life

Fifty 2006 model and fifty 2007 model Sonic Concepts JSATS acoustic transmitters were withheld from implantation throughout the yearling migration season to estimate the life of transmitters implanted in AT fish. Transmitters were surgically implanted in hatchery-reared juvenile Chinook salmon at the Pacific Northwest National Laboratory (PNNL) aquatic research laboratory using procedures similar to those described above. Implanted fish were held indoors in 770 L flow-through tanks (1.29 m diameter × 0.59 m deep) with hydrophones from two Sonic Concepts Model N202 Portable Receiver Nodes suspended in the water column to detect acoustic transmitter signals. Transmitter detections were recorded to a compact flash (CF) card mounted in each portable node. Compact flash cards were downloaded and replaced weekly and node batteries were changed as needed. Implanted fish were held in the tanks until no signals were detected from any of the transmitters.

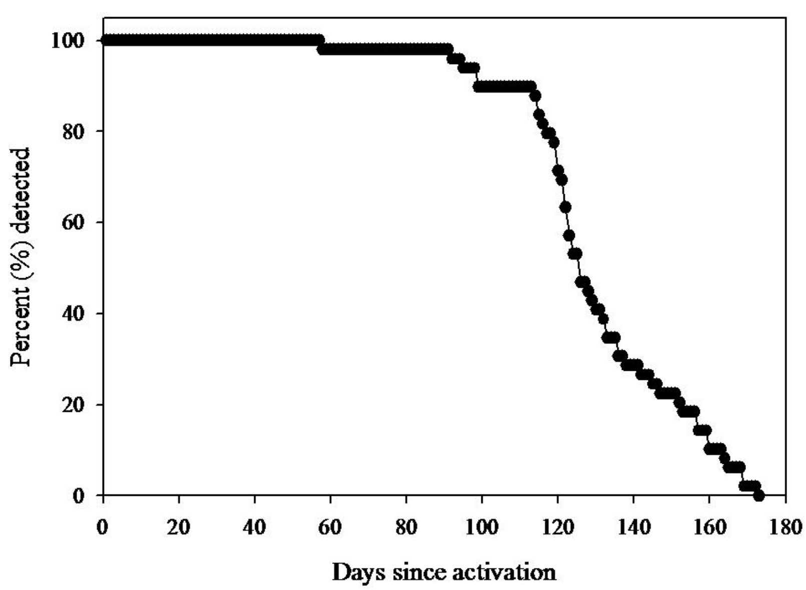
Fifty ATS acoustic transmitters were withheld from implantation throughout the subyearling migration season to estimate the life of transmitters implanted in AT test and AT pilot fish. Transmitters were surgically implanted in hatchery-reared juvenile Chinook salmon at the PNNL aquatic research laboratory and tag life was estimated using the same methods as described for estimating tag life of the Sonic Concepts acoustic transmitters implanted in yearling Chinook salmon.



Appendix Figure B1. Detections of 99 2006-model Sonic Concepts acoustic transmitters each day following activation. Data were used to estimate the life of transmitters implanted in river-run hatchery yearling Chinook salmon released into the tailrace of Lower Granite Dam, 2007.



Appendix Figure B2. Percent of forty-nine 2007 model Sonic Concepts acoustic transmitters detected in the laboratory each day following their activation. These data were used to estimate the life of transmitters implanted in river-run hatchery yearling Chinook salmon that were released into the tailrace of Lower Granite Dam, 2007.



Appendix Figure B3. Percent of 49 Advanced Telemetry Systems acoustic transmitters detected in the laboratory each day following their activation. These data were used to estimate the battery life of transmitters implanted in river-run hatchery subyearling Chinook salmon that were released into the tailrace of Lower Granite Dam, 2007.

APPENDIX C

Methods Used for Detection and Survival Probability Estimates
Tag Effects Study: Statistical Approach

John Skalski and Rebecca Buchanan
Aquatic & Fishery Sciences
Center for Quantitative Science
University of Washington

Introduction

The effect of acoustic tagging on survival of migrating salmonid smolts was explored in a double-tagging study using PIT tags and acoustic tags. Two groups of smolts were collected at Lower Granite, tagged, and released to the Lower Granite tailrace. The control group was single-tagged with PIT tags alone, and the treatment group was double-tagged with both PIT tags and acoustic tags. The objective of the study was to estimate the relative survival (Δ) from Lower Granite to McNary of the double-tagged fish compared to the single-tagged fish, while accounting for tag failure or tag loss. For the following discussion, it is assumed that McNary is the first detection site, and detections at the second detection "site" are composed of all pooled detections downstream of McNary.

The Cormack-Jolly-Seber (CJS; Cormack 1964; Jolly 1965; Seber 1965) model is typically used to estimate survival of PIT-tagged salmonids between dams in the Columbia River. When detections of only a single type of tag (e.g., for single-tagged fish, or using only PIT-tag detections from double-tagged fish), the survival parameter estimated by the CJS model is the joint probability of fish survival and having an intact, operating tag. For this study, if the control fish (single-tagged) and treatment fish (double-tagged) have the same probability of tag loss, then the ratio of the CJS survival estimates to McNary for the two groups based solely on PIT-tag detections would be an unbiased estimator of Δ, the multiplicative effect of acoustic tags on survival. However, it is possible that the double-tagged fish experienced a different probability of PIT-tag loss than the single-tagged fish, because of differences in tagging methods: PIT tags were injected into single-tagged fish, and surgically implanted in double-tagged fish. Thus, the ratio of CJS survival estimates to McNary for the two groups, based only on PIT-tag data, will include tag loss probabilities for the two groups and will be biased for Δ, with an unknown bias.

The bias described above occurs because detections from only one type of tag (PIT tags) were used. However, fish in the treatment group have both PIT tags and acoustic tags. It is possible to use detection data from both types of tags in a two-reach CJS model to estimate the survival of treatment fish to McNary (or the first detection site) separately from tag loss. This can be done by jointly analyzing PIT-tag detections of treatment fish at McNary, and acoustic-tag detections of treatment fish at detection sites downstream of McNary in the CJS model. Under the assumption that loss or failure of PIT tags occurs independently of loss or failure of acoustic tags (either upstream or downstream of McNary), the CJS model yields an unbiased estimator of S_T, the survival of treatment (double-tagged) fish to McNary, regardless of tag loss or failure. This composite approach results in an estimator of Δ that has a better understood bias than the simple ratio of CJS survival estimates based on PIT-tag data alone. Additionally, this approach uses the available data more efficiently and so produces a more precise estimator than basing analysis on PIT-tag detections alone. Finally, this approach is attractive because it follows the original plan of using the downstream acoustic detections to augment the PIT-tag detections.

Methods

The analysis method is based on the following assumptions:

A1. All single-tagged fish have common survival probabilities downstream of Lower Granite, regardless of prior detection history.

A2. All single-tagged fish have common detection probabilities at McNary and at downstream detection sites, regardless of prior detection history.

A3. All double-tagged fish have common survival probabilities downstream of Lower Granite, regardless of prior detection history.

A4. All double-tagged fish with working PIT tags that reach McNary have a common probability of detection at McNary, regardless of prior detection history.

A5. All double-tagged fish with working acoustic tags that reach acoustic arrays downstream of McNary have a common probability of detection at those sites, regardless of prior PIT-tag detection history.

A6. The fate of each tagged fish is independent of the fate of all other tagged fish.

A7. All double-tagged fish have common probabilities of PIT-tag loss or failure between Lower Granite and McNary, and common probabilities of acoustic-tag loss or failure between Lower Granite and McNary.

A8. All double-tagged fish with working acoustic tags have common probabilities of acoustic-tag loss or failure downstream of McNary.

A9. Loss or failure of PIT tags occurs independently of loss or failure of acoustic tags.

Assumptions A1, A2, and A6 are the basic CJS assumptions used in analyzing PIT-tag detections from the control group. Assumptions A3-A6 are the basic CJS assumptions for the treatment fish, applied to both PIT-tag and acoustic-tag detection. Assumptions A7-A9 are necessary for parameterizing tag loss or failure for the treatment group, and for separating survival (or mortality) to McNary from tag loss.

Define the following parameters:

$S_C =$ Survival of control fish from release to McNary;

$S_T =$ Survival of treatment fish from release to McNary;

$S_{P(C)} =$ Probability that the PIT tag in a control fish neither fails nor is lost between release and McNary, i.e., "survival" of PIT tag for control fish;

$R_C =$ Number of fish released in the control group (single-tagged with PIT tags);

$R_T =$ Number of fish released in the treatment group (double-tagged with PIT tags and acoustic tags).

The ratio

$$\Delta = \frac{S_T}{S_C} \tag{0.1}$$

is the multiplicative effect of acoustic tags on survival from release at Lower Granite to McNary. If $\Delta < 1$, then acoustic tags lowered survival over the journey from Lower Granite to McNary.

As demonstrated in the Appendix, if detections from PIT tags only are used with the CJS two-reach model in the presence of tag loss, then the CJS parameter representing survival to the first detection site is actually the joint probability of fish survival and tag "survival" (Table A2 vs. Table A1). This means that for the control group, the CJS "survival" parameter $\left(S_{CJS(C)}\right)$ is actually the product of survival between release and the first site (McNary) and the probability of having a functioning PIT tag at McNary:

$$S_{CJS(C)} = S_C S_{P(C)}. \tag{0.2}$$

Without additional data, it is impossible to separately estimate S_C and $S_{P(C)}$.

Alternatively for the treatment group, if the CJS model is applied to detection histories composed of PIT-tag detections from the first site (McNary) and pooled acoustic-tag detections from downstream detection arrays (and if PIT-tag loss occurs independently of acoustic-tag loss), then the CJS "survival" parameter for treatment fish

$\left(S_{CJS(T)}\right)$ is simply survival of double-tagged fish from release to the first detection site (Table A3 vs. Table A1 in the Appendix):

$$S_{CJS(T)} = S_T. \tag{0.3}$$

The independent loss of PIT tags and acoustic tags allows separation of fish survival from PIT-tag survival in the first reach when both PIT-tag detections and acoustic-tag detections are used.

Define the following statistics:

$n_{1(C)}$ = number of control fish detected on PIT-tag detectors at McNary and on PIT-tag detectors downstream of McNary;

$n_{2(C)}$ = number of control fish detected on PIT-tag detectors at McNary, but not on PIT-tag detectors downstream of McNary;

$n_{3(C)}$ = number of control fish detected on PIT-tag detectors downstream of McNary, but not on PIT-tag detectors at McNary.

$n_{1(T)}$ = number of treatment fish detected on PIT-tag detectors at McNary and on acoustic arrays downstream of McNary;

$n_{2(T)}$ = number of treatment fish detected on PIT-tag detectors at McNary, but not on acoustic arrays downstream of McNary;

$n_{3(T)}$ = number of treatment fish detected on acoustic arrays downstream of McNary, but not on PIT-tag detectors at McNary.

The estimator for the CJS survival parameter for the control group is

$$\hat{S}_{CJS(C)} = \frac{\left(n_{1(C)} + n_{2(C)}\right)\left(n_{1(C)} + n_{3(C)}\right)}{R_C n_{1(C)}}, \tag{0.4}$$

with expected value

$$E\left(\hat{S}_{CJS(C)}\right) = S_C S_{P(C)}. \tag{0.5}$$

The CJS survival estimator is negatively biased for survival of control fish if there is PIT-tag loss or failure after release.

The estimator for the CJS survival parameter for the treatment group is

$$\hat{S}_{CJS(T)} = \frac{\left(n_{1(T)} + n_{2(T)}\right)\left(n_{1(T)} + n_{3(T)}\right)}{R_T n_{1(T)}}, \tag{0.6}$$

with expected value

$$E\left(\hat{S}_{CJS(T)}\right) = S_T. \tag{0.7}$$

The CJS survival estimator is unbiased for survival of treatment fish in the presence of PIT-tag loss, as long as PIT-tag and acoustic-tag detections are used at different sites and PIT-tag loss occurs independently of acoustic-tag loss.
The recommended estimator of Δ is

$$\hat{\Delta} = \frac{\hat{S}_{CJS(T)}}{\hat{S}_{CJS(C)}}. \tag{0.8}$$

The numerator of the estimator of Δ in Equation 1.8 is an unbiased estimator of survival of the double-tagged fish to McNary, while the denominator is a negatively biased estimator of survival of single-tagged fish to McNary, with the bias caused by PIT-tag loss or failure among the control group. The expected value of the estimator in Equation 1.8 is approximately

$$E\left(\hat{\Delta}\right) \approx \frac{S_T}{S_C S_{P(C)}} = \Delta \frac{1}{S_{P(C)}}. \tag{0.9}$$

Thus, if there is no PIT-tag loss or failure among the control group between release at Lower Granite and reaching McNary, then Equation 1.8 provides an unbiased estimate of Δ. Otherwise, Equation 1.8 is positively biased, and the effect of PIT-tag loss on the estimate of Δ may be explored for different hypotheses about tag loss or failure among the control group.

Conclusions

In order to estimate fish survival from release to McNary (first detection site) for double-tagged fish, we recommend using the CJS model to analyze detection histories composed of PIT-tag detections at McNary and acoustic-tag detections pooled across acoustic arrays downstream of McNary. This approach yields a survival estimator that is unbiased and has greater precision than an estimator based on PIT-tag data alone. Using the CJS model to analyze detection histories composed only of PIT-tag data yields a survival estimator that is negatively biased in the case of PIT-tag loss or failure after release. Thus, estimates of the relative survival of acoustic-tagged fish (i.e., double-tagged fish) compared to PIT-tagged fish (i.e., single-tagged fish) will be positively biased if there is tag loss or failure among the single-tagged fish.

References

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-438.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration - stochastic model. Biometrika 52:225-247.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Appendix

Here, the two-reach CJS model is parameterized and the expected value of the typical CJS survival estimator analyzed for three scenarios: PIT-tag data alone without tag loss, PIT-tag data alone in the presence of tag loss, and PIT-tag data combined with acoustic-tag data in the presence of tag loss. Define the following parameters:

$S_1 =$ survival (of fish) from release to the first detection site;

$S_{P1} =$ the probability that the PIT tag remains implanted and operational from release to the first detection site, i.e., "survival" of the PIT tag;

$p_1 =$ the conditional probability of PIT-tag detection at the first detection site, given reaching that site with a functioning PIT tag;

$\lambda =$ the joint probability of (fish) survival from the first detection site to the second detection site and being detected at the second site, conditional on reaching the first site;

$\lambda_P =$ the joint probability of fish survival and PIT-tag survival from the first detection site to the second detection site and PIT-tag detection at the second site, conditional on reaching the first site with a functioning PIT tag;

$\lambda_A =$ the joint probability of fish survival and acoustic-tag survival from the first detection site to the second detection site and acoustic-tag detection at the second site, conditional on reaching the first site.

Define the following statistics:

$n_1 =$ number of fish detected at both the first and second detection sites;

$n_2 =$ number of fish detected at the first detection site but not the second;

$n_3 =$ number of fish detected at the second detection site but not the first;

$n_4 =$ number of fish released but not detected at either detection site.

The estimator of the CJS survival parameter $\left(S_{CJS}\right)$ is the following:

$$\hat{S}_{CJS} = \frac{\left(n_1 + n_2\right)\left(n_1 + n_3\right)}{Rn_1}, \tag{0.10}$$

where R is the size of the release group.

Table A1 shows the possible detection histories and their probabilities in the absence of PIT-tag loss when only PIT-tag detections are used. For this scenario, the expected value of the CJS survival estimator is simply S_1.

Table A1. Possible detection histories and their probabilities using only PIT-tag detections when there is no tag loss.

Detection History Counts	**Detection at MCN (PIT)**	**Detection Downstream (PIT)**	**Probability**
n_1	1	1	$S_1 p_1 \lambda$
n_2	1	0	$S_1 p_1 \left(1-\lambda\right)$
n_3	0	1	$S_1 \left(1-p_1\right)\lambda$
n_4	0	0	$1-S_1+S_1\left(1-p_1\right)\left(1-\lambda\right)$

Table A2 shows the possible detection histories and their probabilities in the presence of PIT-tag loss when only PIT-tag detections are used. For this scenario, the expected value of the CJS survival estimator is $S_1 S_{P1}$, the joint probability of reaching the first detection site and having a functioning PIT tag. Thus, the CJS survival estimator is negatively biased for fish survival.

Table A2. Possible detection histories and their probabilities in the presence of tag loss using only PIT-tag detections. S_{P1} is PIT-tag survival to the first site, and λ_P is the joint probability of fish survival and PIT-tag survival from the first site to the second site, given reaching the first site with a functioning PIT tag, and PIT-tag detection at the second site.

Detection History Counts	**Detection at MCN (PIT)**	**Detection Downstream (PIT)**	**Probability**
n_1	1	1	$S_1 S_{P1} p_1 \lambda_P$
n_2	1	0	$S_1 S_{P1} p_1 \left(1-\lambda_P\right)$
n_3	0	1	$S_1 S_{P1} \left(1-p_1\right) \lambda_P$
n_4	0	0	$1-S_1 S_{P1} + S_1 S_{P1} \left(1-p_1\right)\left(1-\lambda_P\right)$

Table A3 shows the possible detection histories and their probabilities when both PIT-tag detections and acoustic-tag detections are used from double-tagged fish in the presence of both PIT-tag loss and acoustic-tag loss, and under the assumption that PIT-tag loss occurs independently of acoustic-tag loss. For this scenario, the expected value of the CJS survival estimator is S_1.

Table A3. Possible detection histories and their probabilities in the presence of tag loss using PIT-tag detections at the first site and acoustic-tag detections at the second site (or pooled downstream sites). PIT-tag loss is assumed to occur independently of acoustic-tag loss. S_{P1} is PIT-tag survival to the first site, and λ_A is the joint probability of fish survival from the first site to the second site (given reaching the first site), acoustic-tag survival from release to the second site, and acoustic-tag detection at the second site.

Detection History Counts	**Detection at MCN (PIT)**	**Detection Downstream (Acoustic)**	**Probability**
n_1	1	1	$S_1 S_{P1} p_1 \lambda_A$
n_2	1	0	$S_1 S_{P1} p_1 \left(1-\lambda_A\right)$
n_3	0	1	$S_1 \left(1-S_{P1} p_1\right) \lambda_A$
n_4	0	0	$1-S_1 + S_1 \left(1-S_{P1} p_1\right)\left(1-\lambda_A\right)$

APPENDIX D

Detection History Data Tables

Appendix Table D1. Percentages of hatchery yearling Chinook salmon implanted with both an acoustic transmitter and PIT tag (AT fish) and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

		Proportion (%) and number detected (n)					
Release date	Number released	Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
25 Apr	404	13 (53)	15 (62)	4 (17)	26 (105)	25 (102)	7 (29)
26 Apr	397	14 (57)	14 (55)	7(26)	25 (101)	28 (110)	6 (24)
28 Apr	404	18 (71)	13 (54)	5 (21)	25 (101)	29 (118)	8 (34)
1 May	403	21 (85)	12 (48)	5 (19)	25 (102)	22 (89)	5 (22)
3 May	406	13 (53)	6 (23)	4 (18)	21 (85)	20 (83)	7 (27)
5 May	412	9 (37)	16 (64)	10 (43)	24 (98)	22 (92)	8 (33)
9 May	414	22 (90)	27 (110)	4 (17)	23 (96)	23 (95)	6 (24)
10 May	299	27 (81)	20 (59)	4 (13)	26 (78)	18 (54)	4 (11)
12 May	311	26 (80)	9 (29)	4 (11)	24 (75)	18 (57)	4 (13)
15 May	368	22 (81)	15 (55)	2 (9)	29 (107)	22 (80)	6 (22)
Total	3,818	18 (688)	15 (559)	5 (194)	25 (948)	23 (880)	6 (239)

Appendix Table D2. Percentages of hatchery yearling Chinook salmon implanted only with a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

		Proportion (%) and number detected (n)					
Release date	Number released	Little Goose	Lower Monument al	Ice Harbor	McNary	John Day	Bonneville
24 Apr	4,512	9 (425)	13 (609)	6 (260)	34 (1,514)	32 (1,422)	9 (392)
26 Apr	3,769	12 (440)	14 (538)	6 (212)	31 (1,157)	31 (1,162)	9 (322)
28 Apr	3,334	16 (540)	16 (518)	5 (156)	28 (950)	30 (990)	7 (243)
1 May	3,792	18 (664)	10 (365)	3 (132)	30 (1,128)	30 (1,132)	11 (315)
3 May	8,040	11 (857)	3 (265)	3 (251)	27 (2,193)	26 (2,102)	9 (729)
5 May	5,579	8 (461)	11 (638)	7 (417)	26 (1,471)	26 (1,462)	9 (491)
8 May	3,561	18 (658)	27 (965)	4 (141)	25 (878)	25 (880)	8 (302)
10 May	4,773	28 (1,321)	23 (1,093)	4 (197)	30 (1,364)	27 (1,221)	8 (340)
12 May	4,804	22 (1,078)	9 (419)	5 (234)	30 (1,454)	27 (1,319)	8 (385)
15 May	4,550	16 (738)	15 (680)	2 (89)	30 (1,363)	22 (1,021)	6 (284)
Total	46,714	15 (7,182)	13 (6,090)	4 (2,089)	29 (13,472)	27 (12,711)	8 (3,803)

Appendix Table D3. Percentages of AT pilot (85-94 mm) hatchery subyearling Chinook salmon implanted with an acoustic transmitter and a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

		Proportion (%) and number detected (n)					
Release date	Number released	Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
5 June	90	29 (26)	2 (2)	0 (0)	3 (3)	1 (1)	0 (0)
6 June	87	26 (23)	5 (4)	1 (1)	2 (2)	2 (2)	0 (0)
7 June	91	31 (28)	1 (1)	0 (0)	3 (3)	0 (0)	0 (0)
8 June	89	20 (18)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)
9 June	81	25 (20)	0 (0)	2 (2)	1 (1)	0 (0)	0 (0)
12 June	89	31 (28)	3 (3)	2 (2)	3 (3)	0 (0)	0 (0)
13 June	92	26 (24)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
14 June	113	28 (32)	2 (2)	1 (1)	2 (2)	1 (1)	0 (0)
15 June	103	25 (26)	0 (0)	1 (1)	1 (1)	0 (0)	0 (0)
16 June	127	29 (37)	0 (0)	2 (2)	1 (1)	2 (2)	2 (2)
19 June	104	13 (13)	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)
20 June	106	15 (16)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)
21 June	97	24 (23)	2 (2)	1 (1)	0 (0)	0 (0)	0 (0)
22 June	89	10 (9)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
23 June	108	16 (17)	1 (1)	1 (1)	1 (1)	0 (0)	0 (0)
26 June	79	19 (15)	0 (0)	0 (0)	1 (1)	2 (2)	1 (1)
27 June	98	10 (10)	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)
28 June	116	13 (15)	2 (2)	0 (0)	1 (1)	0 (0)	0 (0)
29 June	71	13 (9)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
30 June	59	14 (8)	3 (2)	0 (0)	0 (0)	0 (0)	2 (1)
3 July	40	0 (0)	0 (0)	0 (0)	3 (1)	0 (0)	0 (0)
4 July	84	20 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
5 July	53	8 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
6 July	4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
12 July	2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
13 July	13	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
14 July	12	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	2,097	20 (418)	1 (24)	1 (12)	1 (22)	<1 (9)	<1 (4)

Appendix Table D4. Percentages of AT (> 94 mm) hatchery subyearling Chinook salmon implanted with an acoustic transmitter and a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Proportion (%) and number (n) detected					
		Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
5 June	260	19 (50)	6 (15)	2 (5)	21 (54)	5 (13)	4 (10)
6 June	267	23 (62)	6 (15)	2 (6)	14 (38)	5 (13)	2 (6)
7 June	263	29 (77)	5 (13)	2 (6)	11 (30)	6 (17)	2 (6)
8 June	263	25 (65)	5 (14)	2 (4)	5 (14)	2 (5)	<1 (1)
9 June	271	25 (68)	1 (4)	1 (4)	9 (24)	4 (10)	1 (3)
12 June	261	34 (89)	3 (7)	1 (2)	5 (13)	4 (11)	2 (4)
13 June	270	26 (69)	0 (0)	1 (4)	4 (12)	2 (5)	1 (2)
14 June	308	23 (71)	1 (3)	2 (6)	4 (13)	1 (4)	2 (6)
15 June	323	25 (82)	1 (3)	1 (2)	5 (16)	2 (5)	1 (2)
16 June	270	21 (57)	2 (5)	1 (4)	6 (15)	1 (3)	1 (4)
19 June	328	18 (60)	1 (4)	2 (7)	9 (28)	2 (6)	2 (5)
20 June	247	14 (34)	2 (5)	1 (2)	5 (13)	1 (3)	1 (2)
21 June	273	13 (35)	2 (5)	1 (4)	4 (10)	1 (4)	2 (5)
22 June	320	16 (50)	2 (7)	0 (1)	9 (28)	3 (8)	1 (4)
23 June	302	14 (41)	2 (5)	1 (2)	6 (18)	2 (7)	1 (4)
26 June	337	17 (56)	3 (9)	2 (6)	5 (16)	1 (3)	<1 (1)
27 June	246	15 (37)	2 (4)	1 (2)	5 (13)	2 (5)	<1 (1)
28 June	270	13 (34)	1 (3)	<1 (1)	3 (8)	1 (3)	<1 (1)
29 June	243	17 (42)	1 (3)	1 (2)	3 (7)	1 (3)	1 (2)
30 June	290	19 (54)	2 (7)	2 (6)	2 (7)	1 (4)	0 (0)
3 July	271	21 (56)	3 (7)	1 (3)	2 (6)	1 (3)	1 (2)
4 July	292	21 (62)	2 (6)	< 1 (1)	2 (5)	1 (4)	< 1 (1)
5 July	237	17 (41)	< 1 (1)	< 1 (1)	1 (3)	< 1 (1)	< 1 (1)
6 July	137	20 (28)	1 (2)	1 (2)	1 (1)	0 (0)	0 (0)
12 July	549	8 (43)	1 (6)	1 (3)	< 1 (2)	1 (3)	0 (0)
13 July	329	4 (13)	0 (0)	0 (0)	< 1 (1)	< 1 (1)	0 (0)
14 July	309	4 (13)	0 (0)	0 (0)	0 (0)	0 (0)	< 1 (1)
Total	7,736	18 (1,389)	2 (153)	1 (86)	5 (395)	2 (144)	1 (74)

Appendix Table D5. Percentages of hatchery subyearling Chinook salmon implanted only with a PIT tag and released into the tailrace of Lower Granite Dam that were detected downstream at dams or in the estuary trawl detection system, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Detections (%) of hatchery subyearling Chinook salmon (n)						
		Little Goose	L. Monumental	Ice Harbor	McNary	John Day	Bonneville	Estuary Trawl
5 June	1,096	16 (176)	4 (45)	4 (41)	23 (253)	12 (134)	9 (99)	1 (8)
6 June	1,171	21 (245)	5 (55)	2 (18)	26 (307)	11 (125)	7 (81)	1 (9)
7 June	1,131	22 (249)	5 (52)	2 (24)	23 (257)	11 (122)	7 (78)	1 (6)
8 June	1,081	22 (237)	4 (39)	2 (22)	18 (192)	11 (116)	7 (78)	1 (10)
9 June	1,133	23 (266)	2 (26)	1 (16)	15 (174)	10 (108)	7 (79)	1 (10)
12 June	1,070	20 (215)	2 (18)	1 (10)	12 (131)	6 (63)	5 (55)	< 1 (4)
13 June	1,143	24 (276)	1 (11)	1 (13)	12 (137)	7 (85)	6 (71)	1 (13)
14 June	1,075	22 (236)	1 (10)	1 (11)	12 (128)	6 (65)	6 (60)	< 1 (5)
15 June	895	21 (189)	1 (10)	1 (11)	10 (93)	8 (70)	5 (45)	< 1 (4)
16 June	1,240	19 (238)	1 (12)	1 (8)	11 (139)	7 (88)	4 (54)	1 (7)
19 June	1,225	17 (211)	1 (10)	1 (12)	12 (146)	5 (59)	6 (70)	1 (7)
20 June	906	13 (116)	< 1 (4)	1 (9)	10 (93)	5 (43)	5 (48)	0 (0)
21 June	1,670	6 (106)	1 (12)	< 1 (4)	5 (86)	3 (44)	4 (59)	< 1 (8)
23 June	1,002	10 (99)	1 (9)	1 (14)	10 (96)	5 (54)	6 (62)	1 (6)
26 June	1,412	16 (221)	2 (25)	1 (19)	13 (182)	4 (62)	5 (64)	< 1 (7)
27 June	1,154	14 (167)	1 (15)	1 (15)	12 (134)	5 (55)	4 (44)	1 (9)
28 June	973	16 (155)	2 (22)	2 (16)	12 (112)	4 (40)	4 (41)	< 1 (2)
29 June	386	16 (62)	3 (13)	3 (10)	12 (45)	4 (17)	5 (18)	1 (2)
30 June	616	18 (108)	2 (13)	3 (20)	11 (66)	5 (32)	4 (24)	< 1 (1)
3 July	1,089	19 (202)	2 (24)	1 (15)	7 (71)	4 (40)	3 (29)	< 1 (2)
4 July	649	26 (168)	3 (22)	2 (13)	7 (47)	5 (33)	4 (25)	0 (0)
5 July	605	19 (114)	3 (17)	1 (7)	5 (30)	3 (21)	3 (18)	0 (0)
6 July	1,448	22 (316)	4 (52)	2 (23)	7 (98)	4 (53)	2 (30)	0 (0)
11 July	274	14 (38)	1 (4)	0 (0)	1 (4)	2 (6)	1 (4)	0 (0)
12 July	771	16 (121)	1 (9)	1 (5)	1 (11)	2 (13)	1 (6)	0 (0)
13 July	433	11 (48)	1 (6)	< 1 (1)	2 (7)	1 (6)	0 (0)	0 (0)
14 July	767	13 (98)	1 (11)	1 (4)	2 (13)	2 (15)	< 1 (3)	0 (0)
Overall	26,415	18 (4,677)	2 (546)	1 (361)	12 (3,052)	6 (1,569)	5 (1,245)	< 1 (120)

APPENDIX E: Histological Metrics

Appendix Table E. Description of metrics used in histological evaluations. Except where otherwise noted, all metrics are evaluated by presence/absence.

Metric	Description/biological meaning
Liver	
Liver vacuolation	Measure of the normal glycogen (energy) or lipid/fat stores in liver; primarily glycogen. This is a nutritional measure. Measured on ordinal scale of 1-7.
Liver lymphocytic infiltrates and PV cuffing	Can be an indicator of BKD.
Liver hydropic vacuolation (abbr. Liver HYDVAC):	Water vacuoles in the liver cell. Occurrence may be related to previous exposure to chlorinated hydrocarbons (marine fish) or changes in pH.
Liver coagulative necrosis:	Coagulative necrosis in hepatocytes of liver
Liver eosinophilic hypertrophy (abbr. Liver eosin. Hypertrophy):	Phenomena where hepatocytes stain more eosinophilic than usual, and are hypertrophied; occurrence is often related to degenerative changes.
Liver BKD lesions:	Lesions suggestive of bacterial kidney disease in liver.
Liver Ceratomyxa lesions:	Ceratomyxa shasta-like myxosporeans in liver.
Pancreas	
Pancreatic zymogen	A digestive enzyme measured on an ordinal scale of 0-3. Low or absent pancreatic zymogen indicates that a fish has stopped eating.
Pancreatic atrophy	Evidence that pancreatic cells have shrunk. This metric also indicates that a fish has stopped eating.
Mesenteric adipose content	Fat reserves in the mesentery; measured on an ordinal scale from 0-3. This metric is a nutritional measure..
Pancreatic Inflammation	Inflammatory cell infiltrates in and around the exocrine pancreas.
Small intestine	
Small intestinal mucosal glycogen	Glycogen reserves in the small intestine. This is generally not a good indicator or nutritional status; rated on an ordinal scale from 0-3.
Small intenstinal digesta	Presence/absence of food in the small intestine. This metric is a nutritional measure.
Small intestinal trematode content	When present, small intestinal trematodes appeared to be at commensal levels.
Small intestinal inflammation	Prevalence of intestinal inflammation.
Small intestinal Ceratomyxa	Organisms resembling Ceratomyxa shasta in mucosa of small intestine.
Lower intestine	
Lower intestinal mucosal glycogen levels	Glycogen stores in the lower intestine; rated on an ordinal scale from 0-3. This metric is a nutritional indicator.
Lower intestinal digesta	Presence/absence of food in the large intestine. This metric is a nutritional measure.
Lower intestinal trematodes	If present, levels did not appear higher than normal, and there was no indication that trematodes were causing problems for these fish.
Lower intestinal inflammation	Inflammation in the lower intestine.

Appendix Table E. Continued.

Metric	Description/biological meaning
Heart epicarditis/myocarditis	Either inflammation of the epicardium (epicarditis) or myocardium (myocarditis) in the heart.
Kidney	
Kidney BKD lesions	Indication of BKD response.
Kidney tubule epithelial necrosis	Coagulative necrosis of the epithelium lining the tubules of the kidney nephrons.
Kidney tubule Myxosporea	Unidentified myxosporean infection of the epithelium lining the kidney tubules.
Kidney tubule hydropic vacuolation	Water vacuoles in the kidney tubule cells.
Spleen	
Splenic congestion	Typically indicates a generalized response to stress.
Splenic macrophage aggregates	Normal structures, indicating activity of reticuloendothelial system; rated on ordinal scale from 1-7.
Spleen lymphoid depletion	Reduction in normal proportion of white pulp (lymphoid tissue) to red pump (erythropoietic tissue) in the spleen.
Peritoneum	
Mesenteric chronic inflammation	Inflammation in mesentery; presence probably does not effect mortality; rated as presence/absence.
Mesenteric chronic inflammation severity	Inflammation in mesentery; presence probably does not effect mortality; rated on an ordinal scale from 0-7.
Peritonitis, chronic	Internal adhesions at the site of the incision. When present, there were no obvious signs of an infectious cause such as the presence of large amounts of bacteria; however, an infectious cause could not be ruled out.
Wound healing	
Incision closure	Describes whether or not the incision appears closed over by epidermal cells; 1= closure, 0 = open, no closure.
Skin stratum compactum reknitting	Reknitting or reconnection of the stratum compactum layer in the dermis, where the stratum compactum layer on either side of surgical incision has joined together.
Incision, poor apposition	This parameter shows whether or not there was a poor, uneven apposition between the two sides of the incision; essentially describes poor or uneven (i.e. overlapping, rather than evenly apposed) closure of the two body wall surfaces by the sutures. Poor apposition creates a larger entry point for secondary pathogens to enter the wound site and the peritoneal cavity: 1 = poor 0 = good
Incision, chronic inflammation	Measure of presence/absence of chronic inflammatory infiltrates (e.g. macrophages, lymphocytes) at the incision site.
Incision, chronic inflammation severity	Ordinal measure (0-7) of degree of cellular infiltrates in region of incision, as above.
Dermal musculature necrosis	Measure of residual muscle necrosis at incision site.
Dermal hemorrhage fibrin	Measure of residual hemorrhage or fibrin deposition in area of incision.
Incision adhesions	Adhesions between mesenteries associated with internal organs and the peritoneum in the area of the incision and suture site. Adhesions are usually associated with chronic peritonitis.
Internal organ evulsion through incision and presence of saprolegnia	Evaluated internally and externally; measured as presence/absence.

APPENDIX F

Covariate Analysis of Factors Affecting Survival

Methods

Bivariate and multivariable regression analyses were used to identify factors associated with all observed tag effects. Tag effect was defined as a significant ($\alpha = 0.05$) difference in the mean survival probability between acoustic- and PIT-tagged fish within a release group at a detection site. Relative survival (i.e., mean AT survival probability / mean PIT survival probability) was used as the response variable in the regression models as a measure of tag effect. A relative survival value greater than or equal to one indicated no tag effect because AT fish survived as well as, or better than PIT-tagged fish. A relative survival value of less than one indicated AT fish had a lower probability of survival than PIT-tagged fish. Predictor variables included in the regression models included mean river discharge (kcfs), mean water temperature (°C), release date (ordinal day of year), mean tag burden (%; calculated from weight obtained at tagging), mean Fulton's condition factor (C; calculated from length and weight obtained at tagging), mean fork length (mm; measured at tagging), and median travel rate (km/d).

Using methods similar to those described by Berggren and Filardo (1993) the river discharge and water temperature variables were calculated as averages of their daily averages over the estimated median travel times (i.e., the mean river discharge and mean water temperature experienced by the first 50% of each release group to arrive at each detection site was calculated from daily averages), which were obtained from the Columbia River Data Access in Real Time website (www.cbr.washington.edu/dart). For example, AT fish released into the tailrace of Lower Granite Dam on 24 April had a median travel time of 6 d to Little Goose Dam. The mean river discharge and water temperature experienced by the first 50% of this release group to arrive at Little Goose Dam was calculated from the daily averages of river discharge and water temperature recorded at Little Goose Dam during the 24-30 April period. The use of this method for estimating mean river discharge and mean water temperature ensured that the conditions experienced by the leading half of a release group (up to the arrival of the median fish) were taken into account (Berggren and Filardo 1993).

Time-related factors, such as differences in the physiological development of release groups (Giorgi et al. 1997; Smith et al. 2003) and differing day lengths (Berggren and Filardo 1993), may affect the survival of juvenile Chinook salmon. These factors were addressed in the models by including the ordinal day of year (i.e., 1-365) that fish were released into the tailrace of Lower Granite Dam as a variable.

Tag burden was included as a variable in the models because adverse effects on fish physiology and behavior can increase as the ratio of transmitter weight to fish weight increases (Marty and Summerfelt 1986; Greenstreet and Morgan 1989). Additionally, the physical state of a fish at the time of transmitter implantation may affect its reaction to the transmitter and ultimately its probability of survival. Therefore, Fulton's condition factor:

$$C = (W/L^3) \times 100{,}000$$

where W = weight (g), and L = fork length (mm) was also included in the model. Fork length was included as a variable in the models to determine the effects of implanting fish of various lengths on the survival of acoustic-tagged fish. Mean tag burden, condition factor, and fork length were calculated from all acoustic-tagged fish that were released in each group.

The amount of time taken by fish to travel through the CRB can affect their probability of survival. Fish that take longer to travel through the system may experience greater exposure time to predators, parasites, bacteria, and potentially unfavorable water conditions. Therefore, median travel rate from release at Lower Granite Dam to each downstream PIT tag detection site was calculated for each release group of acoustic-tagged fish and included as a predictor variable in the regression models. Travel rate was used as a response variable instead of travel time to allow for comparisons between reaches of different lengths.

Six regression models (one for each detection site) were possible for both yearling and subyearling AT fish. However, ten or greater AT fish from each release group had to be detected at a PIT detection site to provide reliable estimates of travel rate, river discharge, and water temperature. If fewer than ten AT fish from a release group were detected at a detection site, that group of fish was removed from the regression analyses developed for that detection site. Additionally, regression analyses were not conducted for a detection site if fewer than ten AT fish were detected at that detection site from more than half of the release groups.

The goal of conducting these analyses was to create multivariable models that had minimal multicollinearity among predictor variables, high R^2 values, and meaningful interpretation of the variables retained in the final model. First, bivariate regression models were developed by fitting each predictor variable to the response variable (relative survival) to determine the strength and direction of relationships. Next, all possible combinations of variables were regressed against relative survival to find the multivariable model that best fit the aforementioned criteria. Problematic multicollinearity in the multivariable models was identified by sign changes of regression coefficients (*b*) that were significantly ($\alpha = 0.05$) correlated with relative survival in the bivariate regression analysis and from strong correlations among predictor variables, which were obtained by calculating Pearson correlation coefficients (*r*). Models with problematic multicollinearity or nonsignificant ($P > 0.05$) regression coefficients were removed from further analysis. The remaining model with the highest predictive potential, based on the coefficient of determination (R^2), was retained.

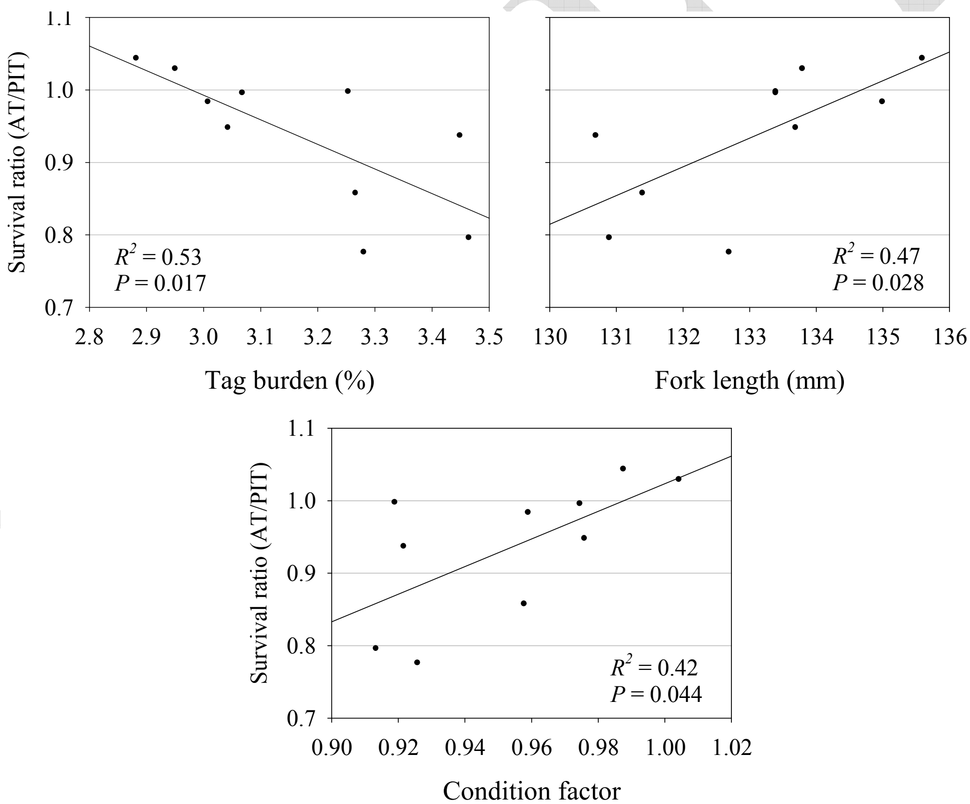
Results

Yearling Chinook Salmon—Bivariate and multivariable regression analyses were conducted on the AT/PIT survival ratio for each reach (i.e., release to dam) where a significant tag effect was observed. Thus, regression analyses were conducted using all release groups for the reaches from release to John Day and Bonneville Dams. Regression analyses were also conducted for the reach from release to McNary Dam, as the difference in survival between acoustic- and PIT-tagged fish in this reach approached significance ($P = 0.054$).

Tag burden, fork length, and condition factor were significantly ($\alpha = 0.05$) correlated with AT/PIT survival ratio in the bivariate analyses for AT yearling Chinook salmon migrating to McNary Dam (Appendix Table F1). Tag burden was negatively correlated with and explained 53% of the variation in the survival ratio (Appendix Figure F1). Fork length and condition factor were positively correlated with and accounted for 47% and 42% of the variation in survival ratio, respectively (Appendix Figure F1). The significant ($P = 0.017$) multivariable model included fork length, water temperature, and river discharge and explained 80% of the variation in the survival ratio (Appendix Table F2). However, strong correlations among predictor variables make interpretation of the multivariable model difficult (Appendix Table F3). Tag burden was highly correlated ($r \geq 0.80$) with release day, water temperature, fork length, and condition factor, and condition factor was highly correlated with release day and water temperature (Appendix Table F3).

Appendix Table F1. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from release into the Lower Granite Dam tailrace to McNary Dam in 2007.

Variable	P-value	R^2	Direction of relationship
Tag burden	0.017	0.53	−
Fork length	0.028	0.47	+
Condition factor	0.044	0.42	+
Water temperature	0.107	0.29	+
Release day	0.163	0.23	+
Travel rate	0.514	0.06	+
River discharge	0.734	0.02	+



Appendix Figure F1. Bivariate relationships between AT/PIT survival ratio and tag burden, fork length, and condition factor for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Appendix Table F2. Significant multivariable regression model for predicting the AT/PIT survival ratio of acoustic-tagged yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Regression Coefficient (*b*)	SE	*t*-value ($b = 0$)	Probability[b] ($b = 0$)	R^2	*P*
Constant	-3.92	1.85	-2.12	0.078	0.80	0.017
Fork length	0.05	0.02	2.96	0.026		
Water temperature	0.07	0.03	1.98	0.095		
River discharge	-0.01	< 0.01	-3.07	0.022		

Appendix Table F3. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable regression analysis to determine the factors associated with the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Release day	River discharge	Water temperature	Travel rate	Fork length	Tag burden	Condition factor
Release day	1.00	0.79	0.99	0.86	0.70	-0.83	0.82
River discharge	0.79	1.00	0.77	0.88	0.66	-0.62	0.47
Water temperature	0.99	0.77	1.00	0.83	0.73	-0.87	0.86
Travel rate	0.86	0.88	0.83	1.00	0.57	-0.59	0.50
Fork length	0.70	0.66	0.73	0.57	1.00	-0.92	0.65
Tag burden	-0.83	-0.62	-0.87	-0.59	-0.92	1.00	-0.90
Condition factor	0.82	0.47	0.86	0.50	0.65	-0.90	1.00

No predictor variables were significantly ($\alpha = 0.05$) correlated in the bivariate analyses with the AT/PIT survival ratio for acoustic-tagged yearling Chinook salmon migrating from release into the Lower Granite Dam tailrace to John Day Dam (Appendix Table FX). The significant ($P = 0.003$) multivariable model, including tag burden and river discharge, explained the most variation (80%) in survival ratio among all possible models (Appendix Table FX). However, direct interpretation of the multivariable model is convoluted because tag burden was highly correlated ($r \geq 0.80$) with release day, water temperature, fork length, and condition factor (Appendix Table FX).

Appendix Table F4. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	*P*-value	R^2	Direction of relationship
Condition factor	0.080	0.33	+
Tag burden	0.120	0.28	–
River discharge	0.190	0.20	–
Fork length	0.248	0.16	+
Water temperature	0.400	0.09	+
Release day	0.454	0.07	+
Travel rate	0.981	< 0.01	+

Appendix Table F5. Significant multivariable regression model for predicting the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	Regression coefficient (*b*)	SE	*t*-value ($b = 0$)	Probability[b] ($b = 0$)	R^2	*P*
Constant	6.65	1.13	5.86	< 0.001	0.80	0.003
Tag burden	-0.60	0.13	-4.60	0.002		
River discharge	-0.02	< 0.01	-4.32	0.003		

Appendix Table F6. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable regression analysis to determine the factors associated with the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	Release day	River discharge (kcfs?)	Water temp. (°C)	Travel rate	Fork length (mm)	Tag burden (% body wt)	Condition factor
Release day	1.00	0.58	1.00	0.90	0.70	-0.83	0.82
River discharge	0.58	1.00	0.55	0.74	0.52	-0.41	0.19
Water temperature	1.00	0.55	1.00	0.88	0.72	-0.85	0.84
Travel rate	0.90	0.74	0.88	1.00	0.62	-0.66	0.59
Fork length	0.70	0.52	0.72	0.62	1.00	-0.92	0.65
Tag burden	-0.83	-0.41	-0.85	-0.66	-0.92	1.00	-0.90
Condition factor	0.82	0.19	0.84	0.59	0.65	-0.90	1.00

No predictor variables were significantly (α = 0.05) correlated in the bivariate analyses with the AT/PIT survival ratio for acoustic-tagged yearling Chinook salmon migrating to Bonneville Dam (Appendix Table FX). Each predictor explained less than 20% of the variation in survival ratio (Appendix Table FX). Additionally, no combination of predictor variables resulted in a significant (α = 0.05) multivariable model.

Appendix Table F7. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to Bonneville Dam in 2007.

Variable	*P*-value	R^2	Direction of relationship
Water temperature	0.213	0.19	+
Release day	0.221	0.18	+
Tag burden	0.314	0.13	–
Fork length	0.325	0.12	+
Condition factor	0.380	0.10	+
River discharge	0.662	0.03	–
Travel rate	0.686	0.02	+

Subyearling Chinook Salmon—Condition factor, tag burden, and fork length of AT≥95 mm FL subyearling Chinook salmon migrating to Little Goose Dam were significantly (α = 0.05) correlated in the bivariate regression analyses with the AT/PIT survival ratio (Appendix Table FX). Condition factor, tag burden, and fork length explained 22, 21, and 19% of the variation in survival ratio, respectively. However, the direction of all relationships between significant predictor variables and survival ratio was inverse of expected. For example, condition factor and fork length were negatively correlated with survival ratio and tag burden was positively correlated with survival ratio (Appendix Table FX). Condition factor, tag burden, and fork length were highly correlated (r > 0.75) with each other and with release day (Appendix Table FX), which may have caused the anomalous correlations with AT/PIT survival ratio. No combination of predictor variables resulted in a significant (α = 0.05) multivariable model.

Appendix Table F8. Results of bivariate analyses of AT/PIT survival ratio for acoustic-tagged (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to Little Goose Dam in 2007. Variables are ordered by *P*-value.

Variable	*P*-value	R^2	Direction of relationship
Condition factor	0.017	0.22	-
Tag burden	0.021	0.21	+
Fork length	0.028	0.19	-
Release day	0.072	0.13	-
Water temperature	0.138	0.09	-
River discharge	0.304	0.05	+
Travel rate	0.521	0.02	+

Appendix Table F9. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable analysis to determine factors associated with AT/PIT survival ratio of acoustic tagged test (AT≥95 mm FL) river-run subyearling Chinook salmon migrating from Lower Granite Dam to Little Goose Dam in 2007.

Variable	Release day	River discharge	Water temperature	Fork length	Condition factor	Tag burden	Travel rate
Release day	1.00	-0.88	0.94	0.82	0.89	-0.89	0.00
River discharge	-0.88	1.00	-0.71	-0.66	-0.67	0.72	0.23
Water temperature	0.94	-0.71	1.00	0.83	0.84	-0.88	0.22
Fork length	0.82	-0.66	0.83	1.00	0.79	-0.98	0.19
Condition factor	0.89	-0.67	0.84	0.79	1.00	-0.90	0.04
Tag burden	-0.89	0.72	-0.88	-0.98	-0.90	1.00	-0.14
Travel rate	0.00	0.23	0.22	0.19	0.04	-0.14	1.00

No predictor variables for AT≥95 mm FL subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam were found to be significantly ($\alpha = 0.05$) correlated with the AT/PIT survival ratio in the bivariate regression analysis (Appendix Table FX). The significant multivariable model that best explained variation in survival ratio of acoustic-tagged subyearling Chinook salmon included river discharge and fork length, and explained 35% of variation in survival ratio ($P = 0.048$; Appendix Table FX). The model indicates that survival ratio increases with increasing river discharge and with increasing fork length of AT≥95 mm FL fish. However, fork length was highly correlated with tag burden and discharge was highly correlated with release day and water temperature (Appendix Table FX) making direct interpretation of the model convoluted.

Appendix Table F10. Results of bivariate analyses of AT/PIT survival ratio for acoustic tagged test (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007. Variables are ordered by *P*-value.

Variable	*P*-value	R^2	Direction of relationship
Travel rate	0.063	0.21	+
River discharge	0.151	0.13	+
Water temperature	0.256	0.09	-
Fork length	0.313	0.07	+
Release day	0.352	0.06	-
Condition factor	0.453	0.04	-
Tag burden	0.597	0.02	-

Appendix Table F11. Results of multivariable analyses of AT/PIT survival ratio for acoustic tagged test (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Regression coefficient (*b*)	SE	*t*-value (*b* = 0)	Probability (*b* = 0)	R^2	*P*
Constant	-4.07	1.90	-2.15	0.05	0.35	0.048
River discharge	0.00	0.00	2.48	0.03		
Fork length	0.04	0.02	2.18	0.05		

Appendix Table F12. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable analysis to determine factors associated with AT/PIT survival ratio of acoustic tagged (AT≥95 mm FL) river-run subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Release day	River discharge	Water temperature	Travel rate	Fork length	Condition factor	Tag burden
Release day	1.00	-0.95	0.98	-0.04	0.61	0.70	-0.73
River discharge	-0.95	1.00	-0.97	0.33	-0.44	-0.77	0.61
Water temp	0.98	-0.97	1.00	-0.18	0.52	0.72	-0.67
Travel rate	-0.04	0.33	-0.18	1.00	0.49	-0.32	-0.29
Fork length	0.61	-0.44	0.52	0.49	1.00	0.44	-0.95
Condition factor	0.70	-0.77	0.72	-0.32	0.44	1.00	-0.70
Tag burden	-0.73	0.61	-0.67	-0.29	-0.95	-0.70	1.00